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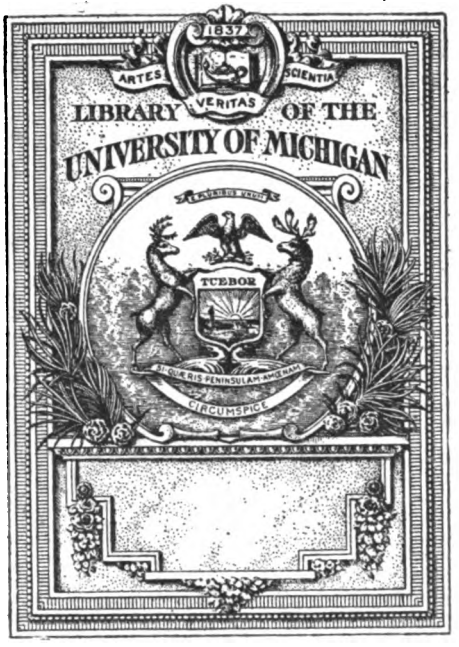

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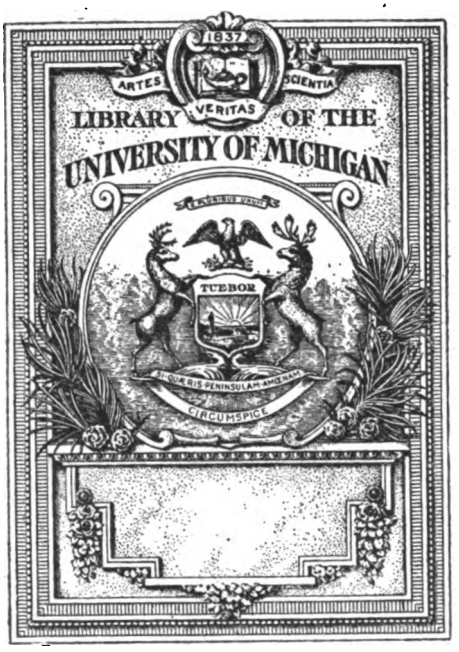

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ANDREW C. LAWSON

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THE CORRELATION OF THE PRE-CAMBRIAN ROCKS OF THE REGION OF THE GREAT LAKES

BY
ANDREW C. LAWSON

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THE CORRELATION OF THE PRE-CAMBRIAN ROCKS OF THE REGION OF THE GREAT LAKES

BY
ANDREW C. LAWSON

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INTRODUCTION

The meeting of the International Geological Congress at Toronto in 1913 seems to have marked a new epoch in the history of our ideas of the pre-Cambrian of the region of the Great Lakes. The papers which were presented at that meeting and which have appeared since then, comprising new field observations extending from Rainy Lake to the Adirondacks and embracing both sides of Lake Superior, not only indicate a renewal of interest in the problems of pre-Cambrian geology,

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but they contain data and hypotheses of prime importance for the solution of those problems.

A review of the results of this new work, together with the more reliable and generally accepted conclusions of earlier investigations, show a very remarkable unanimity among the students of separate districts distributed over the entire region. There still remain, of course, certain outstanding differences of opinion over questions of correlation, and particularly as to the use of terms; but if, for the moment, we disregard names and the correlations which they imply, and focus our attention on the great and fundamental fact of sequence of formations and events, an astonishing sameness of result appears in a score of districts where more or less detailed work has been done. It is the purpose of this paper to make use of this similarity of sequence, together with a new hypothesis to be formulated in the sequel, in an effort to correlate in a comprehensive way the geological history of these districts with one another. The result of this effort is summarized in the tabulation which accompanies the paper.

UTILITY OF TENTATIVE CORRELATIONS

Some writers, notably Collins[1] of the Geological Survey of Canada, incline to the view that we can make real progress only by abandoning for the present all effort at a general classification of the pre-Cambrian formations and concentrating our attention on particular sections which are favorable for study, and which are near enough to permit of sure correlations from one to the other; and so gradually widen an area within which a classification may be established unvitiated by the errors of distant correlation.

This policy as voiced by Collins is a safe one for the survey to lay down, and if pursued consistently will undoubtedly lead to positive results. It is a matter for congratulation that we have this prospect of close and detailed work on the part of the Canadian geologists, and it is to be hoped that more men will engage in it. In the vastness of the pre-Cambrian terranes of Canada and the multiplicity of problems which they present, there is every justification for the survey devoting more of its energies to this field.

But the method advocated by Collins, while most commendable, is not the only one which will contribute to the solution of the general

[1] A classification of the pre-Cambrian formations in the region east of Lake Superior, Congrès géologique international, 1913.

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problem. Workers in particular closely grouped fields may ignore the work going on in other fields and publish their observations as if the latter did not exist, and so, perhaps, promote the intensity of their own activity; but this attitude after all is only an expression of the principle of subdivision of labor, and implies that others must do the equally important work of collation, comparison and generalization. Every competent attempt at generalization from a reasonable amount of data is a step in advance in so far as it corrects the errors of earlier efforts. The discarded generalizations, the succession of which creates so much disgust in the minds of some, are merely hypotheses which have served their purpose and have been supplanted by others which, in most cases, are nearer the truth. The normal procedure in scientific progress is the modification of hypotheses, and the discarding of generalizations as expressed in correlation tables, etc., is only an exemplification of this procedure. The odium which attaches to erroneous correlation tables fades away when we regard them in their true light as hypotheses put forward to stimulate inquiry as to their validity.

These hypotheses are the more necessary and the more useful in geology because of the vastness of the field of observation, the expense attaching to the work, and in pre-Cambrian geology, because of an international boundary which precludes survey officers of one country from fully familiarizing themselves with the field relations in the other. These conditions make it impossible for the individual geologist thoroughly to test a hypothesis that may explain his own particular field, and he is under the necessity of publishing it in order to secure cooperative criticism from other fields. In most other sciences the individual worker may more conveniently put his hypothesis to the test before publication, and there are in these sciences doubtless as many discarded hypotheses as in geology, though perhaps not so many have been published.

Having thus persuaded myself that tentative generalizations are a useful if not a necessary part of the method of advancing our knowledge of pre-Cambrian geology, I shall proceed to review briefly some phases of our present knowledge of this field and to formulate still another correlation table. I am moved the more to do this because of the recent publication of a correlation table by Allen and Barrett,[2] to certain parts of which I dissent on the ground that it does not take sufficient cognizance of the relationships established in other fields.

[2] Journ. Geol., vol. 23, no. 8, p. 689, 1915.

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CRITERIA OF PRE-CAMBRIAN CORRELATION

The table which I offer for consideration is designed to be more than an alternative to that of Allen and Barrett, in that it exemplifies the application of a principle in the correlation of the pre-Cambrian, which if true, should be of great interest and service to students in this general field.

The work of Allen and Barrett on the pre-Cambrian sequence and structure of the Gogebic range is of a high order. These geologists appear to have been actuated, however, by the principle, laid down by Collins, of every man confining himself to his own bailiwick; and they do not discuss the relation of their own very important discoveries to the general problem of the classification and correlation of the pre-Cambrian. Yet, in the use of such terms as Huronian and Animikie for major subdivisions of their sequence, they imply correlations and conclusions which are at variance with the recent results of Collins[3] obtained on the north side of Lake Huron by methods quite as thorough and reliable as their own. Indeed, it would be difficult to find a more striking illustration of the infelicity of the exclusive method, of ignoring what others are doing, than is afforded by a comparison of the use of terms in the papers by Collins on the one hand and by Allen and Barrett on the other.

The correlation table here presented contains fifteen columns showing the pre-Cambrian sequence in as many different districts distributed over the region of the Great Lakes from Rainy Lake to the Adirondacks. The sequence in every district, with one exception, column XI, is practically undisputed. The columns may be placed side by side in various ways so as to suggest various correlations according to the views of the correlator and the guiding principle of correlation adopted by him. The difficulty of finding principles sufficiently reliable to establish correlations in the pre-Cambrian is well known. Those that have been used by geologists up to the present are chiefly: (1) The principle of lithologic similarity and the community of conditions of deposition inferred from this similarity. (2) The principle of the similarity of sequence. (3) The principle of coincidence of unconformities in the sequence. (4) The principle of irruptive contacts.

By diligent and repeated application of these principles numerous attempts at correlation have been made, each one seeking to improve on

[3] The Huronian Formations of the Temiskaming Region, Canada, Geol. Survey of Canada, Mus. Bulls. nos. 8, 1914, and 22, 1916.

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its predecessor as new similarities or dissimilarities were detected, as the members of the sequence increased in number, and as new unconformities or irruptive contacts were discovered. The Keewatin was segregated from the Huronian on the basis of its dissimilarity and the intrusive relations of the Laurentian granite gneiss. The iron-bearing rocks of the south side of Lake Superior were correlated with the Animikian on the basis of lithologic similarity and their unconformable relation to the Keweenawan above and to an older complex below. The Keweenawan of the north shore has been satisfactorily correlated with the rocks so named on the south shore on the basis of lithologic resemblance. The Huronian has been divided into three parts by two unconformities discovered within the original Huronian terrane and the correlative of these parts is claimed to have been found in various districts on the basis of lithologic resemblance, sequence and coincidence of unconformities. In this way much progress has been made and our knowledge of the pre-Cambrian has advanced greatly in the last three decades.

It is evident, however, when we review the literature and note the wide differences of opinion regarding the correlation of some undisputed sequences, that the principles hitherto invoked are not wholly adequate for the purpose. When fossils were found in the limestones of Steeprock Lake in 1911, it was my hope that the same forms might be found in similar limestones on the south side of Lake Superior and so confirm the correlation tentatively adopted. This expectation, however, has not yet been realized.

HYPOTHESIS OF TWO PERIODS OF GRANITIC INVASION

In the correlation table here formulated a new hypothesis is introduced and used as an aid to correlation, which, if it is true, resolves much of the doubt which has troubled students of pre-Cambrian geology. This hypothesis states that in post-Keewatin time there were two and only two periods in which great granitic batholiths were developed in the earth's crust in the region of the present Great Lakes.

It is intended in this hypothesis to exclude certain acid "red rocks" found intrusive in the Keweenawan as not batholithic masses and as easily distinguishable ordinarily from the granites to which reference is here made. It is also intended in each batholithic period to include all of the various satellitic rocks that pertain to granites, such as pegmatites, aplites, etc., and also certain sequences in the ir-

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ruptive process connected presumably with magmatic differentiation. In general, there is little danger of confounding the various manifestations of batholithic development, such as a sequence of plutonic rocks from basic to acid, of one period with those of the other when both are represented in the same field. Where the batholithic assemblage of only one period is represented in a particular field there may be doubt; but this may usually be resolved by an appeal to other means of correlation with neighboring fields where granites of both periods are represented. Moreover, it seems not improbable that purely petrographical distinctions between the granites of the two periods may be recognized which will aid in their discrimination.

APPLICATION OF THE HYPOTHESIS

The justification of the hypothesis of two and only two granitic assemblages in the post-Keewatin rocks of the region of the Great Lakes is the fact that in the greater number of the districts represented in the accompanying tabulation there actually are two granites widely spaced in time. The hypothesis states that the earlier granite in every district was formed during one and the same general period of time, and that the later granite belongs to another period, the same for all districts. These two granitic assemblages have frequently been confused by a reference of both of them to the Laurentian, but with the increase of detailed studies their separation in time has become apparent in many districts.

Northwest of Lake Superior.—In my work on the northwest side of Lake Superior in 1911 I was so impressed with the importance of this separation that, in order to secure its recognition, and so do away with the confusion which had arisen from the indiscriminate reference of all granites to the Laurentian, I proposed that the latter term be retained for the older assemblage and a new term, Algoman, be employed to designate the later assemblage. On the northwest side of Lake Superior there are six separate and well distributed districts which have been more or less carefully studied, and for each of which we have the necessary data for the formulation of the geological column in the proper chronological sequence. These are: Rainy Lake, Steeprock Lake, Thunder Bay, Gunflint Lake, Vermilion Lake, and the Mesabi Range.

Running through all of these districts is a relatively persistent series of formations comprising conglomerate, quartzite, graywacke,

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slate, and lenses of iron formation and iron ore. This is recognized in the Mesabi, Vermilion, Gunflint and Thunder Bay districts as the Knife Lake slate and Ogishke conglomerate. From Rainy Lake to Steeprock Lake, and beyond to the eastward, the series is continuously exposed. No one questions the identity of the series in the several districts, and it seems fairly certain that it is the product of continuous sedimentation in a definite, unbroken period of time. Temporarily I shall refer to it as the Seine Series and to the corresponding division of time as the Seine Epoch, without prejudice to any more acceptable designation that may be claimed for it later on the basis of correlation. The present distribution of the remnants of the Seine Series, taken in connection with its remarkably uniform lithologic habit, warrants the belief that originally it must have covered an area in this portion of the region of at least 10,000 square miles as a continuous body of sediments.

In all of the districts named above, the Seine Series rests upon the eroded surface of a complex consisting of the Keewatin invaded by granite and granite gneiss of varying facies, with the usual accompaniment of pegmatites, aplites and other differentiation products of batholithic development. This granite and granite gneiss may most conveniently be known as Laurentian in accordance with prevailing usage. It is therefore certain that throughout all of the studied districts in the portion of the region lying to the northwest of Lake Superior, the earth's crust was invaded by granite in time long antecedent to the deposition of the Seine Series and that this granite is post-Keewatin in age. It is most probably all of the same age, i.e., it was all formed in the same large division of time which, in the chronological scale, may be known as the Laurentian Revolution.

Now the Seine Series is, in every one of the six districts named, itself cut by granite and granite gneiss of varying facies with pegmatites, aplite and other differentiation products, constituting a granitic assemblage which, from its vast areal extent, may be regarded as a manifestation of batholithic invasion. To this granite I have given the name of Algoman in a comprehensive sense, so that the period of time in which it was formed may be known as the Algoman, a term co-ordinate with Laurentian in the chronological scale.

It is thus again certain that in all the studied districts northwest of Lake Superior the earth's crust was invaded by granite in time subsequent to the deposition of the Seine Series. It is equally certain that this Algoman granite long antedates the Animikian Series, of

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the original Animikie area, since these rocks may be observed in four of the districts resting on the eroded surface of the granite in relations so clear that they have never been questioned. In the Rainy Lake and Steeprock Lake Districts the Animikian is absent.

There is no room for doubt, therefore, that on the northwest side of Lake Superior the Algoman granite was formed within the space of time between the close of the Seine Epoch and the beginning of the Animikian. It is highly probable on the basis of areal continuity that in all the districts the Algoman granite is the manifestation of one and the same general disturbance and batholithic invasion of the earth's crust. The assumption that this is so is involved in the use of the term Algoman as a designation for these rocks considered as a constitutent part of the earth's crust and in the use of the same term as a designation for a subdivision of geological time.

From the foregoing discussion it is apparent that the Laurentian and Algoman granites afford us two splendid datum planes along which we may correlate from district to district with a confidence proportionate to the validity of the hypothesis of a definite proper age for each granite. In the correlation table columns I to VI, representing the sequences in the different districts, are placed side by side with the granites arranged each on a horizontal line. The correlation thus suggested is that which is generally accepted for the non-plutonic formations of the pre-Cambrian of the northwest side of Lake Superior.

South of Lake Superior.—On the south side of Lake Superior four of the more important and best-known districts, namely, Gogebic, Crystal Falls, Menominee, and Marquette, have been selected for consideration in the correlation table. In each of these districts there is found a group of formations comprising a basal quartzite and an overlying dolomite. In the Gogebic district these are known as the Sunday quartzite and the Bad River dolomite, in the Crystal Falls and Menominee districts as the Sturgeon quartzite and the Randville dolomite, and in the Marquette district as the Mesnard quartzite and the Kona dolomite. All the geologists who have studied these districts are now agreed as to the identity of this pair of formations in all four districts and their correlation is not questioned. The quartzite and dolomite, by whatever local name known, together represent a definite stratigraphic horizon and a definite period of time. Now the quartzite in all four districts rests with a basal conglomerate upon the eroded surface of granite-gneiss which has been referred to the Laurentian, or upon the Keewatin into which the latter is intrusive. It is there-

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fore fairly certain that the group comprising the quartzite and dolomite is later than this Laurentian granite gneiss throughout the four districts.

Resting unconformably on the quartzite-dolomite group in all four districts is another group comprising in the Gogebic district the Palms quartzite, graywacke and slate, the Ironwood iron formation, and the Tyler slates; in the Crystal Falls district the Ajibik quartzite, the Vulcan iron formation and the Hanbury slates; in the Menominee district quartzite, Vulcan iron formation and Hanbury slates; and in the Marquette district the Ajibik quartzite, the Siamo slate and the Negaunee iron formation. Here, again, there is little doubt as to the correlation of this group of variously named formations throughout all four districts. The group, with local volcanic admixtures, represents a definite stratigraphic horizon and a definite period of time which is the same in all districts.

In the Gogebic district the group is cut by the Presque Isle granite, as Allen and Barrett have recently shown,[4] and in the Menominee district the group is also cut by granite. It is therefore certain that, at a time later than the accumulation of this group of variously named formations, there was a plutonic invasion of the earth's crust by granite on the south side of Lake Superior.

Thus we have on the south side of the lake, as on the northwest side, two and (so far as we know) only two periods of batholithic invasion. The corresponding granites serve as on the northwest side to separate the geological column into three great divisions, one antecedent to the first granite, the second between the two granites and the third subsequent to the second granite. It is the essence of the hypothesis which I here advance as a tentative principle of pre-Cambrian correlation, that the two granite invasions of the south side of Lake Superior are chronologically equivalent to the two granite invasions of the northwest side, each to each.

In accordance with this hypothesis the columns expressing the undisputed sequence in the Gogebic, Crystal Falls, Menominee, and Marquette districts are placed in the tabulation with the two granites on the same time-horizons as the two granites of the northwest side of the lake. It follows, if the hypothesis is true, that the group of variously named formations on the south side, comprising the Tyler and Hanbury slates, the Ironwood, Negaunee, and Vulcan iron formations, and the Palms, Siamo, and Ajibik formations, are the correlatives of the

[4] Journ. Geol., vol. 23, no. 8, Nov.-Dec., 1915.

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group of variously named formations on the northwest side comprising the Seine slate, quartzite and conglomerate, the Knife slates, Agawa iron formation, and Ogishke conglomerate of the northwest side. It follows also from the recent work of Allen and Barrett[5] that the Copps Formation, the Michigamme slate, the Bijiki iron formation, and the Goodrich quartzite of the south side are the correlatives of the Animikian of the northwest side of Lake Superior.

North of Lake Huron.—Coming now to the Canadian territory extending from Lake Huron to Lake Temiskaming, there are three general districts in each of which the sequence of the pre-Cambrian rocks has been for the most part clearly established. These are the north shore of Lake Huron, Sudbury, and Lake Temiskaming. In all three districts it is now agreed that in post-Keewatin time there were two distinct periods of granitic invasion. It is also undisputed that one of these invasions occurred in time long antecedent to the deposition of the great body of sedimentary rocks now called the Temiskamian (Sudbury) series, and that the second period of granitic invasion is later than that series. This fact was well known to Logan and precisely described by him in the following words:

> The intrusive granite occupies a considerable area on the coast of Lake Huron, south of Lake Pakokagaming. It there breaks through and disturbs the gneiss of the Laurentian Series and forms a nucleus from which emanates a complexity of dykes, proceeding to considerable distances. As dykes of a similar character are met with intersecting the rocks of the Huronian Series (Temiskamian of Miller and Knight), the nucleus in question is supposed to be of Huronian age, etc.[6]

It seems clear that the older of these granites is what Logan called Laurentian and that it is older than the Temiskamian (Sudbury) series. The later granite cuts the Temiskamian, as is described by Logan, Miller, Coleman, and Collins. In the Sudbury district the Temiskamian (Sudbury) series is invaded by granite and the conglomerate of the series contains boulders of granite, although the basement is not exposed. In the Cobalt district the Temiskamian rests on the eroded surface of the Laurentian granite and is itself invaded by the Lorrain granite.

In a recent paper Collins[7] has shown that the later, or Killarney, granite also cuts the Bruce series.

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[5] *Op. cit.*

[6] Geology of Canada, p. 58, 1863.

[7] Geol. Survey of Canada, Mus. Bull. no. 22, 1916.

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It thus seems pretty certain that the territory extending from Lake Huron to Lake Temiskaming, and including the Lake Huron, Sudbury, and Cobalt districts, suffered granite invasion at two widely spaced periods. These two periods of granitic invasion separate the sequence of epigene rocks throughout these three districts into three parts, precisely in the same way as the two granites on the south side of Lake Superior do, and it seems probable that they are chronological equivalents each to each.

If this be true, then it follows that the Temiskamian and Bruce series both fall into the middle of the three great divisions of time, that is, they were deposited in the period between the degradation of the Laurentian and the invasion of the region by the Killarney or Lorrain granite. The relations of the Temiskamian to the Bruce series have not yet been satisfactorily established, but it seems probable that the Bruce series is the equivalent of the Sturgeon quartzite and Kona dolomite, etc., of the south side of Lake Superior; while it is equally probable that the Temiskamian is the equivalent of the group of variously named formations on the south side comprising the Tyler and Hanbury slate, the Ironwood, Negaumee, and Vulcan iron formation, the Palms and Ajibik formations, etc., and therefore the correlative of the Seine Series on the northwest side of Lake Superior. The Cobalt Series appears then with little question to be the equivalent of the Copps, Michigamme, etc., on the south side and of the Animikian of the northwest side.

Southeastern Ontario and Adirondacks.—In Southeastern Ontario there is an older granite gneiss, the Laurentian, cutting the Keewatin and Grenville series, and a later, Moira, cutting the Hastings series, which rests upon the eroded surface of the Laurentian. These two granites, by the hypothesis here advanced, are the respective chronological equivalents of the two granites on the north shore of Lake Huron, on the south side of Lake Superior and on the northwest side; and the Hastings series is either the correlative of the Temiskamian, as Miller and Knight assert, as well as of the Tyler-Hanbury-Palms-Siamo-Ajibik, etc., and of the Seine; or the correlative of the Bruce series.

In the Adirondacks, according to Cushing,[8] there are two granites of widely different ages, the Laurentian intrusive in the Grenville, and the Picton, itself undeformed, cutting the Laurentian after the deformation of the latter.

[8] Am. Journ. Sci., vol 39, pp. 288–294, March, 1915.

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Summary.—It thus appears that in every one of the fifteen districts, extending over a belt of the continent nearly a thousand miles long and covering both sides of the Great Lakes, we have at least one and not more than two periods of granitic invasion well established. The older granite is represented in all fifteen districts; while the later granite is found in thirteen districts, failing to appear in the Crystal Falls and Marquette, although in the last-named district more discriminating study may yet show its presence. In neither of the two districts in which only one granite is found is there any doubt as to the period to which it belongs. We may safely conclude, therefore, that in every one of the fifteen districts, considered individually, geological time is blocked out into three grand divisions by the two granite invasions: the pre-granitic, the inter-granitic and the post-granitic. It is the essence of the hypothesis here set forth that these three divisions of time, which are so well established in the individual districts, are the same in all of them, there being but one pre-granitic, one inter-granitic and one post-granitic period represented by the known epigene rocks throughout the entire region from Rainy Lake to the Adirondacks.

EVENTS CONNECTED WITH GRANITIC INVASION

Wherever the earth's crust is known to have been extensively invaded by granite, an important concomitant condition has been the uplift of the region affected and the inauguration of a prolonged period of degradation, culminating in the removal of the cover from extensive areas of the granite. Wherever in the course of time sedimentation resumed its sway, the resumption was not effective until the region had been reduced to a surface of low relief. The time necessary for the invasion of a region by granite is unknown, but it may well have been a long drawn-out process. The stripping of the cover of the granite, however, and particularly the reduction of a high region to low relief, requires a long time in the geological sense; and the interval of no deposition, between the sediments resting on the worn surface of the granite and the sediments into which the granite is intrusive, constitutes an unconformity of a major order. We may for practical purposes take the appearance of a worn surface of granite upon which as a basement sedimentary strata rest as *prima facie* evidence of a major unconformity. Now we have such a major unconformity well revealed on the northwest side of Lake Superior in the

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superposition of the Steeprock series upon the granite of the first, or Laurentian, invasion; on the south side of Lake Superior in the superposition of the Sturgeon quartzite upon the Laurentian; and on the north side of Lake Huron in the superposition of the Bruce series upon the Laurentian.[9]

Similarly we have another major unconformity equally well established on the northwest side of Lake Superior in the superposition of the Animikian upon the granite of the second, or Algoman, invasion; on the south side of Lake Superior in the superposition of the Michigamme (Copps, etc.) upon the second granite (Presque Isle); and on the north side of Lake Huron in the superposition of the Cobalt series upon the second granite (Lorrain, probably the same as the Killarney).

Thus, when by hypothesis we correlate chronologically the pairs of granites each to each in the various districts of the tabulation, we are in reality correlating in every case a group of interconnected events of the first magnitude comprising: 1. The invasion of the crust by granite. 2. The uplift of the region. 3. The reduction of the region to low relief. This of course greatly strengthens the hypothesis since it increases the improbability of there having been a multiplicity of chronologically different granitic invasions each with its induced uplift and prolonged period of degradation. It also justifies the use of such terms as Epilaurentian and Eparchean for subdivisions of geological time, since no sediments can have accumulated in any of the districts for a long period after each granitic invasion, these periods being recorded in terms of erosion. Geologists who are concerned only with the sequence of rocks may dispense with these terms, but those who have to deal with the subdivision and correlation of geological time defeat their purpose if they ignore those large periods in which no sediments are known to have been deposited.

DEPARTURES FROM UNANIMITY

It is interesting to note that for the most part the sequences and correlations which are set forth in the tabulation are those which are generally accepted; and for the Canadian territory they represent the same general conclusions as have been published by Miller and Knight,[10] except that these writers have not recognized the dual composition of the Huronian system. There are, however, a few instances

[9] Collins, Geol. Survey of Canada, Mus. Bull. 8 and 22, 1916.

[10] Ont. Bur. Mines, 22, 2, p. 126, 1914.

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in which the table differs from the views held by other geologists, and to these brief reference may now be made.

As to sequences, it is first to be noted that Leith[11] is of the opinion that in the Mesabi district there is a third granite which cuts the Animikian. I have, however, in a former paper[12] pointed out how doubtful the evidence of the age of this granite is and, as my skepticism has deepened, I have omitted it from the table.

In the Lake Huron section, also, I have taken the liberty of differing with Collins in his interpretation of the sequence. In doing this I feel that I have not done violence to any direct evidence which he has adduced as to the superposition of the Bruce series upon the Temiskamian. The hypothesis of two and only two periods of granitic invasion has been used to determine what the real sequence is. I have placed the Bruce series earlier than the Killarney granite and the Cobalt series later, and suggest that the Bruce series lies below the Temiskamian, there being no very satisfactory evidence to the contrary.

In southeastern Ontario there is doubt as to whether the Hastings Series is the correlative of the Bruce or the Temiskamian. In the table I have followed Miller and Knight who correlate it with the Temiskamian.

My most serious difference, however, is with Allen and Barrett, not as to the sequence on the south side of Lake Superior, but as to the correlation of the rocks there with those on the northwest side. As a result of some excellent field studies these geologists found[13] that in the Gogebic district the rocks heretofore referred to the Animikian really comprise two series separated by a major unconformity, involving the uncovering and degradation of the Presque Isle granite. This granite is the second of two granites which occur in the district and the major unconformity corresponds to the Eparchean Interval. According to the principle of correlation here advanced, the rocks which follow the Eparchean Interval, namely, the Copps formation, should be correlated with the Animikian of Thunder Bay. Allen and Barrett, however, correlate the Tyler slate, etc., into which the Presque Isle granite is intrusive, with the Animikian, and make the Copps formation and its equivalents post-Animikian, separated by a major unconformity. This correlation involves the notion of three great granitic

[11] U. S. G. S., Mon. 43, p. 411.

[12] Comptes Rendus Cong. géol. internat. XII, 1913, p. 367.

[13] Journ. Geol., vol. 23, no. 8, 1915.

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invasions in the Lake Superior districts and three major unconformities, and this I hold to be a misconception of the geological history of the region.

On the south side of Lake Superior the local correlations advocated by Allen, which I have for the most part followed in the table, are not wholly accepted by Leith. The difference of view is fully set forth in recent papers by these writers and need not be restated, since they do not affect seriously the main hypothesis of this paper.

PETROGRAPHICAL DISCRIMINATION OF THE TWO GRANITES

It would be a matter of great interest and importance if petrographical criteria could be formulated whereby the Laurentian and Algoman plutonic rocks could be discriminated; but it is probable that our studies of these rocks are too little advanced to make such a discrimination reasonably certain. Nevertheless, since a beginning at this discrimination has to be made, I venture to offer some suggestions to this end, based chiefly on my own observations:

1. The Laurentian granite is in general more uniform and monotonous in mineralogical composition than the Algoman granite.

2. The Algoman granite has usually undergone magmatic differentiation to a marked degree and, therefore, has a larger range of facies than the Laurentian, being in many areas syenitic rather than granitic.

3. The Laurentian granite had been as a rule subject to deformation before the Algoman granite came into existence, and therefore may in general be expected to show more pronounced deformational effects.

4. The Algoman granite is in many extensive areas perfectly massive and unfoliated and this is rarely true of the Laurentian.

5. The Laurentian granite is in many areas bleached in appearance, whereas the Algoman granite appears fresh and in many cases reddish-colored.

6. The phenomena of viscous flow is more often exemplified in the Algoman granite than in the Laurentian.

7. The minerals nepheline, titanite, apatite, and garnet are perhaps more abundant in the Algoman rocks than in the Laurentian.

8. Intrusive phenomena at the contact with encasing rocks are usually clear-cut and pronounced in the case of the Algoman granite and are more obscure in the case of Laurentian granite.

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9. The metamorphism of the rocks encasing the Algoman granite is for rocks of pre-Laurentian age additive to an earlier metamorphism, and for rocks of post-Laurentian age not.

SUBDIVISIONS OF TIME—NOMENCLATURE

Accepting now the hypothesis of two periods of granitic invasion, there remains the question of nomenclature. This has to do with the classification of assemblages of rocks and with the subdivision of geological time, and the names must be appropriate to both. I have shown that pre-Cambrian epigene rocks fall into one or the other of three grand divisions of time, and for these divisions it is clear that we must have distinctive names. For the first or pre-Laurentian division I proposed[14] many years ago the term *Ontarian,* and this still appears to me to be the best term to adopt. It is objected by Miller and Knight[15] that this term has been used as a synonym for Silurian. But this synonym appears to have been stillborn; and fortunately so, for its use would be a burdensome superfluity. The word is not mentioned in the recent work[16] by Schuchert on Historical Geology; nor is it used either in the text or in the tabulation of his more technical paper[17] presented at the Toronto meeting of the International Geological Congress. Similarly, Ulrich appears to have no use for the term as a synonym for Silurian in his papers.[18] If these authorities on the classification of the Paleozoic and many other writers who might be cited ignore the word, we may regard it as discarded and so available for the use which I suggested in 1889. As for the substitute, Loganian, proposed by Miller and Knight,[19] that is effectively disbarred by the general use of the name *Logan* for the sills of Lake Superior.[20]

Applied to the rocks formed in this period of time, Ontarian ranks as a system and embraces the Coutchiching, Keewatin, and Grenville series.

For the second grand division of pre-Cambrian time the term Huronian is undoubtedly the most fitting, as well as the most thor-

[14] The Internal Relations and Taxonomy of the Archean of Central Canada, Bull. Geol. Soc. Am., Dec., 1889.

[15] Revision of pre-Cambrian Classification in Ontario, Journ. Geol., vol. 23, 1915.

[16] Pirsson and Schuchert, A Text-book of Geology, Part II, 1915.

[17] The Delimitation of the Geologic Period, etc., Cong. géol. internat., 1913.

[18] E.g., Revision of the Paleozoic Systems, Bull. Geol. Soc. Am., vol. 22, pl. 27, 1911.

[19] *Op. cit.*

[20] The Laccolithic Sills of the Northwest Coast of Lake Superior, Geol. and Nat. Hist. Surv. Minn., Bull. no. 8, 1893.

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oughly established by the rules of priority and respect for the pioneer workers in this field. From the point of view of stratigraphy Huronian is the name of a system and embraces the Bruce Series of Lake Huron and its equivalents as well as the Temiskamian and its equivalents. By adopting these two terms, the first proposed by Collins[21] in 1914 on behalf of the Geological Survey of Canada and the second by Miller[22] in 1911, we avoid the confusion which attaches to the terms Upper and Lower Huronian. Coleman[23] has sought to substitute Sudburian for Temiskamian but the latter term has priority and should be retained.

For the third of the grand divisions of pre-Cambrian time represented by epigene rocks I propose, as I have done in previous papers, the retention of the term Algonkian. A name is needed and I know of no better use to which the term Algonkian can be put. The name is, I am well aware, in bad repute and nearly meaningless, but I hope it may be retained to serve the purpose for which it was originally intended, namely, to designate the pre-Cambrian rocks laid down in post-Archean time, and as a name for the corresponding period. Thus defined, Algonkian is a system embracing the Animikian and the Keweenawan. This system might with propriety be included in the Paleozoic, to the great simplification of our general scheme of classification.

The Ontarian period is separated from the Huronian by a long lapse of time in which no epigene rocks were formed in the region considered, nor anywhere else that we have cognizance of. Geological processes not less important and even more interesting than sedimentation were, however, in operation; and the record of events and of the passage of time is just as clearly marked as it is in other periods by the accumulation of strata. These events, from the point of view of their distribution in time, comprise: (1) The development of batholithic magmas accompanied by uplift and acute deformation of the crust, and the solidification of these into vast bodies of granite. (2) The prolonged degradation of the region and its reduction to a surface of low relief. The rocks formed during the first of these two time-divisions constitute so important an element in the structure of the earth's crust that we can scarcely discuss the problems which they present without the retention of the term Laurentian, which has been

[21] The Huronian Formations of Temiskaming Region, Canada, Geol. Survey of Canada, Mus. Bull. no. 8, p. 26.

[22] Eng. and Min. Journ., Sept. 30, 1911, p. 648.

[23] Ont. Bur. Mines, 23, pl. 1, p. 205, 1914.

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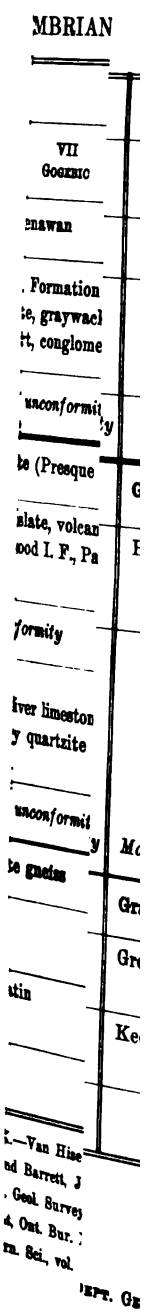
so long applied to them, and which was adopted by the International Committee[24] some years ago. If the name be retained for the rocks, as nearly all geologists conversant with this field are agreed, it seems proper and convenient to use the same term for the time-division in which they were formed. The second division of the lapse between the Ontarian and the Huronian is recorded in terms of erosion only. We have no rocks to discuss or to name. But to complete the time-scale and so keep our ideas on the subdivision of geological time clear, it is desirable that we should name this period, and I have in a former paper suggested that it be designated the Epilaurentian Interval.[25]

Similarly the Huronian is separated from the Algonkian by the time necessary for the development of the Algoman granite, with its concomitant diastrophism, and by the succeeding period in which the region was reduced to a surface of low relief. These time-divisions I have designated the Algoman[26] and the Eparchean Interval.[27] The last-mentioned term is much preferable to Epalgomian suggested by Schuchert[28] as a substitute for the earlier name, because the interval separates the great Archean Era from the Paleozoic. There can be no doubt that historically the Huronian is a subdivision of the Archean, and its relations to the Algoman are so similar to the relations of the Ontarian to the Laurentian, that it is most appropriate to group this dual set of relations and geological conditions together under the comprehensive term Archean. In this sense the term designates an era of time truly and characteristically archaic, even from a geological point of view. The general plan of continental growth in Paleozoic time is usually regarded as having been inaugurated with the Cambrian, but in fact it began with the Animikian. At the close of the Eparchean Interval the vast continental platform, upon which the Paleozoic rocks rest, had been completed. The early Cambrian continent of Walcott[29] was but a slightly modified phase of the continent upon which the Animikian strata were deposited. It was Animikian sedimentation that ushered in the Paleozoic Era. Previous to the Eparchean Interval the physiography of the continent had been wholly different, and its growth had proceeded on other lines. Events



[24] Journ. Geol., vol. 13, 1905.

[25] A Standard Scale for the pre-Cambrian rocks of North America, Cong. géol. internat., XII, 1913.

[26] Cong. géol. internat. XII, 1913.

[27] Bull. Dept. Geol. Univ. Calif., vol. 3, no. 3, 1902.

[28] Text-book of Geology, p. 445, 1915.

[29] U. S. G. S. 12th Ann. Rpt., 1, 1890–91.

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belonged to an entirely distinct era—the Archean. Its history is a record of physical movements which cannot be discussed in terms of life, and the palaeontologists should refrain from insisting on their nomenclature in a field in which they do no work. The labor of harmonizing the views of geologists who know something of this great field is difficult enough without having to struggle with an inappropriate classification injected by those who contribute nothing to the solution of its problems. To me the terms Archeozoic, Early Proterozoic and Late Proterozoic[30] are meaningless and confusing. Whatever meaning they may have to anyone is necessarily visionary; and I question the advisability of teaching visions to beginners in geology.

[30] Pirsson and Schuchert, Textbook of Geology, Pt. II, pp. 444–445, 1915.

Transmitted March 30, 1916.

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UNIVERSITY OF CALIFORNIA PUBLICATIONS
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Vol. 10, No. 2, pp. 21-24, 1 text-figure Issued October 3, 1916

A NEW MUSTELID FROM THE THOUSAND CREEK PLIOCENE OF NEVADA

BY

EMERSON M. BUTTERWORTH

UNIVERSITY OF CALIFORNIA PRESS
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A NEW MUSTELID FROM THE THOUSAND CREEK PLIOCENE OF NEVADA

BY
EMERSON M. BUTTERWORTH

The collections made by the University of California expedition to the Thousand Creek region of Nevada in the summer of 1915 include a mustelid form differing markedly from previously known types. It is desirable to place on record a description of this addition to the Great Basin fauna in order that the information may be available for studies involving the whole faunal assemblage of the Thousand Creek Pliocene.

The writer wishes to express his appreciation for the kind criticism and guidance of Professor John C. Merriam, under whose direction this work has been executed.

TAXIDEA NEVADENSIS, n.sp.

Type specimen an imperfectly preserved mandible, with P_4, M_1, and M_2; no. 22290, Univ. Calif. Col. Vert. Palae.; from the Thousand Creek Pliocene of Thousand Creek, Nevada.

Diagnostic characters: teeth robust, P_4 with accessory cusp posterior and external to the protoconid; protoconid, paraconid, and metaconid of M_1 forming an approximately equilateral triangle, with the cutting shear poorly developed; heel of M_1 large, with peg-like hypoconid, and well-developed entoconid; M_2 nearly circular in cross-section, but with four imperfectly developed tubercles.

The new mustelid form is known by a single mandible, specimen 22290, representing an animal intermediate in size between the Recent badgers and the martens. Due to the fragmentary nature of the material, discussion of generic and specific characters must be confined to the dentition. Imperfect preservation also precludes the

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submission of any but inferential data regarding the teeth anterior to P_4.

Judging from the crowding of the entire dentition anteroposteriorly and the difference in size between the root of P_4 and the alveolus of P_3, it is to be assumed that the premolars of specimen 22290 have suffered reduction in number and dimensions, consisting in part in the elimination of P_1.

P_4, the sole complete representative of the premolar series, is robust and possesses a cusp posterior and external to the protoconid. This cusp is prominent in the Procyonidae and other carnivore phyla, but seems to reach its highest development in the mustelid genera *Martes* and *Taxidea*.

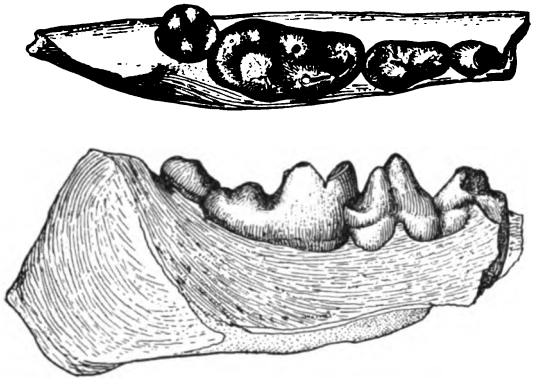

Fig. 1. *Taxidea nevadensis*, n. sp. Type specimen, no. 22290, × 2. Outer and occlusal views of lower dentition. Thousand Creek beds, Thousand Creek, Nevada.

M_1 is heavy and possesses a rudimentary shear. The paraconid and protoconid are of equal size, and with the slightly smaller metaconid form an approximately equilateral triangle. The paraconid is clearly mediad of the median anteroposterior line of the tooth. The heel of M_1 is larger than that observed in any of the described mustelid forms with the exception of *Meles*, the Old World badger. The heel is somewhat trilobate in form. The hypoconid and entoconid are exceptionally well developed, and the posterior region is elevated to form a horseshoe-shaped ridge.

M_2 is nearly circular in cross-section, and probably single-rooted. It is inserted at an angle of about 15° to the occlusal surface of the heel of the carnassial, bringing its crushing face mediad of the median anteroposterior line of the dentition. This character is possibly attributable to individual variation. The crushing surface of the tooth

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is basin-like and irregularly cuspate around the periphery, with the protoconid, metaconid, hypoconid, and entoconid faintly defined.

The unmistakable differences presented by the second lower molar are sufficient to separate the new mustelid from the Procyonidae, the only other phylum of the Carnivora possessing characters close enough to justify comparison. Though there can be no question as to its mustelid affinities, the Thousand Creek form seems markedly different from any other representative of the group. Resembling the modern badgers in its generic characters, specimen 22290 shows the following noteworthy contrasts to the Recent *Taxidea taxus neglecta* of North America: (1) The heel of M_1 of the Thousand Creek form is relatively larger in every dimension than the heel of this tooth in *Taxidea*. (2) In *Taxidea* the tubercles of the heel are much more highly specialized for a cutting function. (3) In *Taxidea* the metaconid is slightly less prominent and is posterior to the protoconid, while the metaconid of the fossil tooth is located nearly as far forward as the protoconid. The general structure of the carnassial is, however, much alike in the two forms, and the structure of the last premolar is identical.

Fundamental differences exist between the fossil mustelid and *Meles*. The simple spike-like P_4 of the Old World badger is in marked contrast to the bicuspate P_4 of the form from the Thousand Creek. The former has the cutting shear of the carnassial well developed, the latter exhibits a more primitive structure of this part of the tooth. In *Meles* the metaconid of M_1 is situated far posterior to the protoconid and the markedly basin-like heel is cuspate only around the border of the tooth, while the metaconid of the fossil tooth is located almost as far forward as the protoconid, and the heel has no pronounced basin.

Lutra, Lutreola, and *Mephitis* possess dental characters widely divergent from those of the Thousand Creek mustelid. These characters preclude any possibility of close relationship to the form under discussion.

The fossil form resembles *Taxidea* in the structure of the lower carnassial and of P_4, though there occur notable differences of proportions. It resembles *Meles* in the ratio between the heel dimensions and the anterior portion or triangle of the carnassial, but differs from the latter form in the conformation of the heel of this tooth and also in respect to the number of cusps of P_4.

It is evident that the Thousand Creek form is more closely related to *Taxidea* than to *Meles,* as differences of structure are of higher rank

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than differences of proportion. This conclusion is consistent with the evidence of geographical distribution. *Meles* is an Old World type; *Taxidea,* a genus characteristic of the New World, is found living in the region where the fossil form occurs. While the structure of the specimen from the Thousand Creek shows close relationship to *Taxidea,* the difference existing in the conformation and proportions of the heel of M_1 indicate that the fossil form represents a group distinct from the modern American badgers. While it is probable that a new group of at least subgeneric value has been here described, definite classification must await more complete structural representation.

MEASUREMENTS

	T. nevadensis Type specimen, Thousand Creek	T. taxus (*a*) Recent, California	M. taxus (*b*) Recent, Germany
Length anterior side P_4 to posterior side M_2	18.5 mm.	29	29.
P_4, anteroposterior diameter	6	9	7.1
M_1, anteroposterior diameter	9.5	14	16
M_1, transverse diameter at protoconid	5	6	5.5
M_1, anteroposterior diameter of heel	5	5	7
M_1, transverse diameter of heel	4.5	6.2	7

(*a*) 4937 Mus. Vert. Zool.
(*b*) 21980 Mus. Vert. Zool.

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THE OCCURRENCE OF ORE ON THE LIMESTONE SIDE OF GARNET ZONES

BY

JOSEPH B. UMPLEBY

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THE OCCURRENCE OF ORE ON THE LIMESTONE SIDE OF GARNET ZONES*

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Introduction

Contact metamorphic ore deposits comprise a type of particular interest because in their geologic occurrence and mineralogical makeup they are intermediate between normal fissure veins and magmatic segregations. During the last sixteen years much attention has been given to them by students of ore genesis and ideas concerning their origin have passed through many stages of development. Their general occurrence at or near igneous contacts affords the common ground that they are genetically related to intrusive masses, but concerning the details of this relationship wide diversity of opinion exists. Does the intrusion merely supply heat to the meteoric circulation, or does it supply the metamorphosing solutions? Is the metamorphism

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coincident with intrusion, or subsequent to the solidification of a magma shell? Does the magma supply silica, alumina and iron for the lime silicates, or are these concentrated from the invaded rocks either by a reduction in volume or by meteoric waters approaching the contact? Is the attack of meteoric waters on the solidified but still hot intrusive an important factor? Does the metasomatism proceed by constant volumes? Do the lime-silicates and sulphides develop simultaneously and have they a common source? These are the principal questions now under discussion. Each of them seems to have been answered satisfactorily for individual deposits, but the problem remains how far one pattern may fit the many known occurrences, and what factors determine diversities within the type.

Any adequate conception of the genesis of contact deposits must be based on the constant relationships which they exhibit, but must be sufficiently elastic to allow for observed diversities. Thus, to add either descriptions of peculiar features of individual deposits, or to point out relationships so often recurring as to be scarcely fortuitous, is to make a contribution to our knowledge of the subject, even if the genetic significance be not fully comprehended or be incorrectly stated.

Statement of Thesis

This paper is an endeavor to point out a common, perhaps a general, spacial relationship between ore and garnet zones in the contact deposits of the North American Cordillera. It is certain that in many deposits the ore bodies favor the limestone rather than the intrusive side of the garnet zone. In several places the ore comes directly up to the igneous contact, but so far as is known to the writer no clear occurrence has been described where barren lime-silicate rock continues outward far beyond such ore. In the case of engulfed blocks of limestone which have suffered metamorphism the limestone side of the garnet mass is toward the central part of the block, and here ore is found in several localities. In some of these cases all of the limestone has disappeared but the ore is centrally situated.

In the following paragraphs this relationship is pointed out in brief descriptions of several contact deposits, and finally its bearing upon modern theories is suggested.

Examples

Washington Camp, Arizona.—The ore deposits at Washington Camp occur locally on the border of a great island-like mass of lime-

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stone surrounded by granitic rocks comprising the main part of Patagonia range.[1] The sedimentary beds dip and strike diversely in different places, but the dip is prevailingly westward at angles of 30 to 90 degrees. The deposits are tabular replacements in limestone both remote from and near to the igneous contact "and have not been observed in any instance to extend ever so slightly into the surrounding granite." The common gangue is garnet, with which the metallic minerals, chalcopyrite, sphalerite and to a minor extent galena, are intimately associated. It is particularly noteworthy, however, that "the ore-body accompanying a contact garnet zone is always on the inside of the zone, that is, between the main body of the garnet ledge and the limestone, and not between the garnet ledge and the granite."[2]

Crosby[3] states further that "obviously enough, the ores, as we now have them, are due to a metasomatic impregnation and replacement of the limestone against and in the massive garnet ledge."

The deposits of Washington Camp, therefore, clearly exemplify the formation of ore on the limestone side of garnet zones. It is perhaps worthy of note that here there has been no endomorphism, a feature in which these deposits are different from several of the others which are described.

Silverbell, Arizona.—In the Silverbell district is a series of limestone blocks of Paleozoic age completely surrounded by alaskite, alaskite porphyry, biotite granite, andesite and quartz porphyry, intruded in the order named.[4] The intrusion of the alaskite porphyry and the biotite granite was followed by intense sericitization and silicification of these rocks and by the development of great masses of garnet, quartz and wollastonite in the adjacent limestone. "Following close upon these solutions came metal-bearing magmatic waters, which impregnated porphyry, granite and alaskite with cupriferous pyrite, and deposited in the garnet zones chalcopyrite and copper-bearing pyrite that make important bodies of contact metamorphic ores." Veins containing lead-silver ores also occur. Endomorphism is represented by a widespread silicification of the intrusions and a local development of garnet and epidote of igneous-rock derivation. The common section from the boundary of the intrusive rock to the limestone is "three to ten feet thick, of solid garnet and quartz, with

[1] Crosby, W. O., The Limestone-granite contact-deposits of Washington Camp, Arizona, Trans. Am. Inst. Min. Engrs., vol. 36, pp. 626-646, 1906.

[2] Crosby, W. O., *op. cit.*, p. 632.

[3] *Op. cit.*, p. 641.

[4] Stewart, C. A., The geology and ore-deposits of the Silverbell Mining District, Arizona, Trans. Am. Inst. Min. Engrs., vol. 43, pp. 240-290, 1912.

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varying amounts of wollastonite, and microscopic diopside. This is gradually replaced by garnet rock with veins and bunches of marble, and the latter becomes more abundant until we find marble with lenses and stringers of garnet and associated minerals, and these become less numerous until a pure marble remains."[5] "Parts of an ore-body may be one hundred feet or more from an intrusive rock; but some portion of every ore mass is close to the contact with one of the two above-named igneous rocks. Usually there is a five to ten-foot band of garnet rock between ore and porphyry."[6] "The ore-minerals are definitely later than most of the gangue-minerals, and occur commonly as veinlets in the garnet-quartz-calcite mass, or disseminated through it."[7]

Seven Devils, Idaho.—The rocks of the Seven Devils district comprise slate, quartzite, limestone and a vast amount of associated greenstone invaded and metamorphosed by a quartz diorite phase of the Idaho granite and capped locally by Columbia basalt.[8] The ore deposits are in typical contact zones situated in part along the external contact of the quartz diorite but principally adjacent to engulfed blocks of limestone. Garnet, epidote and quartz are abundant gangue minerals and bornite and chalcopyrite are the principal sulphides. In the Queen, Blue Jacket and Arkansas mines the ore occurs on the limestone side of garnet zones across which veinlets of chalcopyrite and bornite in a quartz gangue connect with the igneous mass on a dip of about 15 degrees. Mining development along these veinlets has ceased in most places at the igneous contact, but they are known to extend locally twenty-five or thirty feet into the quartz diorite without noticeable diminution in size or change in character. One locality where the veinlets are particularly well shown and are closely spaced is in the Queen No. 1, Intermediate stope. See figure 1.

In the Peacock Mine the ore occurs in the central part of a large garnet-epidote area bordered on the east and west by diorite and on the south by a green porphyritic rock believed to be an engulfed portion of the greenstone series. The main sedimentary contact lies a few hundred feet to the north across an area of normal diorite. Thus it is suggested that an engulfed block of limestone determined

[5] Stewart, C. A., *op. cit.*, p. 272.

[6] *Ibid.*, pp. 280–281.

[7] *Ibid.*, p. 282.

[8] Lindgren, W., The gold and silver veins of Silver City, De Lamar and other mining districts in Idaho, Twentieth Ann. Rept., U. S. Geol. Survey, Pt. 3, pp. 249–253, 1900. Umpleby, J. B., Reconnaissance examination, 1915. Report in preparation.

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the development of the garnet-epidote mass at the Peacock Mine, a suggestion confirmed by the occurrence of marble in diamond-drill cores which come from the deposit, although the location and direction of the hole is not known to the writer. The point of particular interest is that the ore-body occurs in the central part of the garnet mass.

The Seven Devils deposits exhibit both exomorphism and endomorphism, the latter being clearly shown by the stringers and replacement bodies of epidote in the diorite several feet from limestone contacts.

Velardeña, Mexico.—The Velardeña district is an area of folded Cretaceous (?) limestone overlain by andesitic tuffs and flows and traversed by andesitic dikes.[9] The principal intrusive rocks are dikes

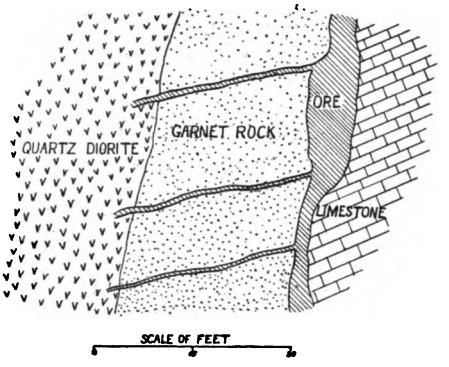

Fig. 1. Transverse section showing relations of ore to limestone and quartz-diorite in Intermediate Stope, Queen No. 1 Mine, Seven Devils, Idaho.

and necks of alaskite and trachytic alaskite accompanied or closely followed by extensive injections of dioritic rocks. All of the intrusive rocks have caused metamorphism and at a time "definitely subsequent to intrusion," as shown by extensive endomorphism. The ore deposits are of varied character and clearly indicate successive stages of deposition. "Sulphides began to be deposited with the lime-silicates, but the chief sulphide deposition followed the lime-silicate period directly, with quartz as principal gangue."[10]

The Copper Queen is the principal copper ore-body of the district and consists of three main pipes in metamorphic rock at the contact of the diorite intrusion. The principal sulphides are cupriferous

[9] Spurr, J. E., and Garrey, G. H., Ore-deposits of the Velardeña District, Mexico, Econ. Geol., vol. 3, pp. 688–725, 1908.

[10] *Op. cit.*, p. 724.

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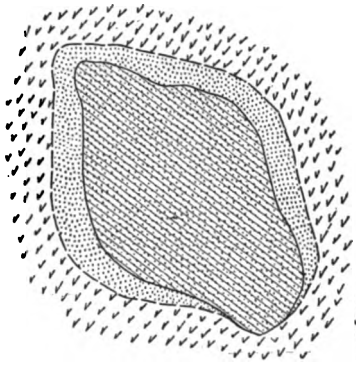
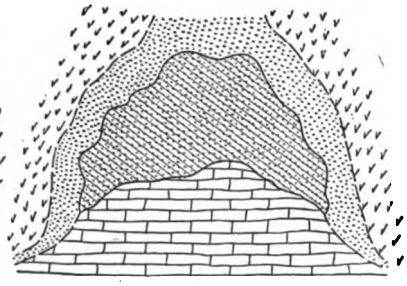
pyrite, sphalerite, and galena. The relation of the ore to garnet rock and limestone in this deposit is clearly shown by Prescott in the illustrations reproduced as figures 2 to 5.[11] Prescott uses these figures to illustrate the occurrence of ore at points where limestone projects



UPPER HORIZON

Fig. 2.

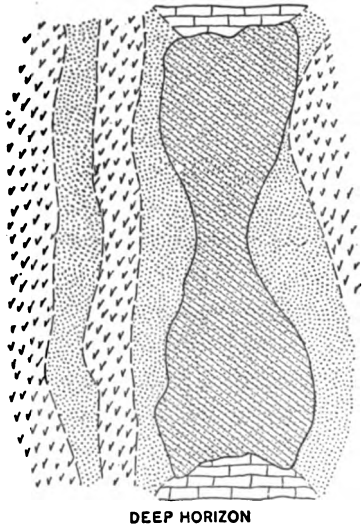


INTERMEDIATE HORIZON

Fig. 3.

LOWER HORIZON

Fig. 4.



DEEP HORIZON

Fig. 5.

Generalized plan of ore chimney at Copper Queen Mine, Velardeña, Durango, Mexico. After Basil Prescott, Econ. Geol., vol. 10, p. 62, 1915.

[11] Prescott, Basil, Some observations on contact metamorphic deposits, Econ. Geol., vol. 10, pp. 55–69, 1915.

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into the intrusive mass, but they are also most pertinent to the present discussion. In figures 3 and 4 the occurrence of ore on the limestone side of the lime-silicate zone is evident. In figure 5 the central limestone has been changed to ore, but its former extent into the area now ore is clearly shown by the relations at the top and bottom of the figure. In figure 2 the ore occurs in the central part of a lime-silicate mass which in the plane of the section is surrounded by the intrusive rock.

Dolores Mine, Mexico.—The Dolores Mine, near Matehuala, S. L. P., Mexico, is situated in an area of Mesozoic limestone, overlain by shale, which forms a great half-dome down faulted on the east.[12] Cutting the sedimentary rocks in the central part of the field are two masses of quartz monzonite. Both of the intrusives have caused noteworthy metamorphism, but about the northern, or Cabriza body, contact rock is especially abundant and widespread. The contacts of the intrusive masses are very irregular and much of the lime-silicate rock has formed at the expense of quartz monzonite, although perhaps most of it is of limestone derivation. The metamorphic minerals include pyroxene, garnet, vesuvianite, wollastonite, fluorite, quartz, and the metallic sulphides, chalcopyrite, pyrite, arsenopyrite, pyrrhotite, blende and galena. Cupriferous pyrite is the most important ore mineral. Careful study has revealed a definite sequence in mineral formation as follows:[13] 1, aluminous pyroxenes; 2, aluminous garnet (grossularite) and vesuvianite; 3, wollastonite; 4, lime-iron pyroxene (hedenbergite); 5, lime-iron garnet (andradite); 6, fluorite, quartz and metallic sulphides (and actinolite and hornblende); 7, metallic sulphides (and quartz and fluorite); 8, calcite. As the calcite is quite certainly residual from the limestone, it is clear that in the Dolores deposit the metallic sulphides were among the last metasomatic minerals developed and formed later than the lime-silicates.

The paper above cited does not describe in detail the spacial relationship of the ore bodies to the limestone and monzonite, although it is stated that they "occur largely at the very contact, frequently with limestone as one wall."[14] In the paper by Prescott,[15] however, sketches of the ore chimney at Dolores Mine, reproduced herein as figures 6 to 8, are pertinent. Figures 7 and 8 are clearly illustrative

[12] Spurr, J. E., Garry, G. H., and Fenner, C. N., Study of a contact metamorphic ore deposit: The Dolores Mine, at Matehuala, S. L. P., Mexico, Econ. Geol., vol. 7, pp. 444–484, 1912.

[13] *Ibid.*, p. 444.

[14] *Ibid.*, p. 446.

[15] *Op. cit.*, p. 65.

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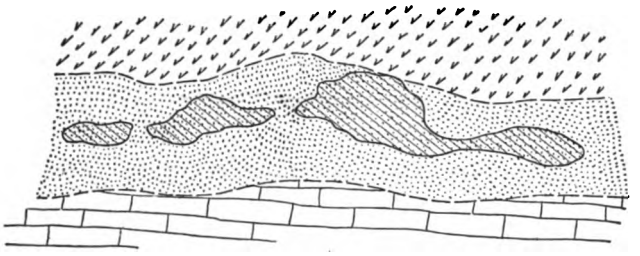
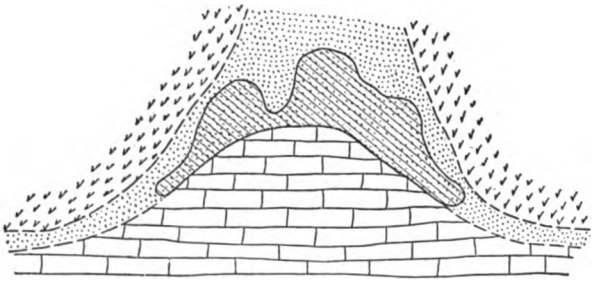


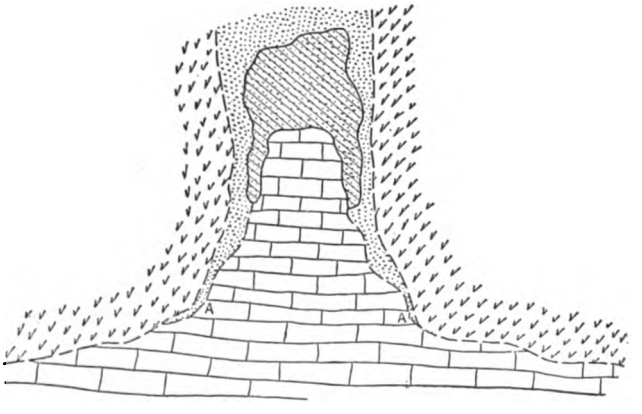
UPPER HORIZON.

Fig. 6



INTERMEDIATE HORIZON.

Fig. 7



DEEP HORIZON.

Fig. 8

Generalized plans of ore chimney at Dolores Mine, Matehuala, San Luis Potosi, Mexico. After Basil Prescott, Econ. Geol., vol. 10, p. 65, 1915.

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of the occurrence of ore on the limestone side of garnet zones. The relations shown in figure 6 do not support the general idea, but it is introduced because it represents a part of the same chimney of ore shown in the other two figures and has value as a check to sweeping generalizations. Within the area represented by it the writer would expect to find clear evidence of replacement of the silicates by the sulphides.

Mackay, Idaho.—The contact metamorphic copper deposits at Mackay, Idaho, occur well within a mass of granite porphyry which has invaded folded strata of Carboniferous age.[16] Several engulfed blocks of limestone occur in the vicinity of the ore deposits and have been variously metamorphosed so that some are bordered by only a narrow margin of marble, others are more than half changed to lime-silicate rock, and still others are completely transformed to garnet-diopside rock and ore. Marmorization accompanied intrusion but the intense metasomatism followed the fracturing of a thick magma shell. In many places the granite porphyry bordering included limestone masses is extensively changed to garnet-diopside rock.

The ore in the Copper Bullion Mine occurs along the margins of a block of limestone several hundred feet long and is separated from the granite porphyry by a zone of garnet-diopside rock from three or four to more than twenty-five feet wide. Marble forms the other wall, but this gives way within a few feet to normal limestone. The relations are illustrated in figure 9.

The Alberta ore bodies, situated along a pronounced fault which traverses the igneous mass, comprise two groups of branching chimneys which occur in the central parts of large garnet areas (fig. 10). Here no central limestone body remains, and the occurrence is interpreted as representing the limiting stage of ore deposition on the limestone side of a garnet zone which surrounds an engulfed block. A study of the ores shows that the sulphides locally are contemporaneous with the garnet crystals but that most of them are of distinctly later development.

Whitehorse Copper Belt, Yukon.—The rocks of the Whitehorse district comprise Carboniferous limestone largely destroyed by three distinct igneous invasions, the principal of which, though of variable composition, is predominantly hornblende granite.[17] The larger

[16] Umpleby, J. B., The genesis of the Mackay Copper Deposits, Idaho, Econ. Geol., vol. 9, pp. 307–358, 1914. The ore deposits of the Mackay Region, Idaho, Prof. Paper, U. S. Geol. Survey (in preparation).

[17] McConnell, R. G., The Whitehorse Copper Belt, Yukon Territory, Can. Geol. Survey, No. 1050, 63 pp., 2 pls., 2 figs., 8 maps, 1909.

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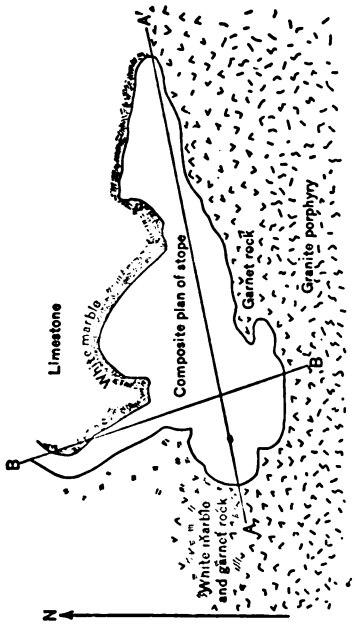

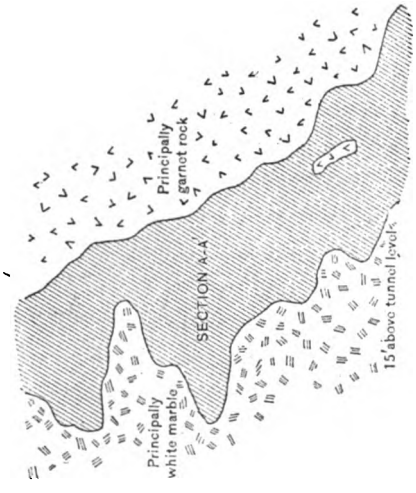

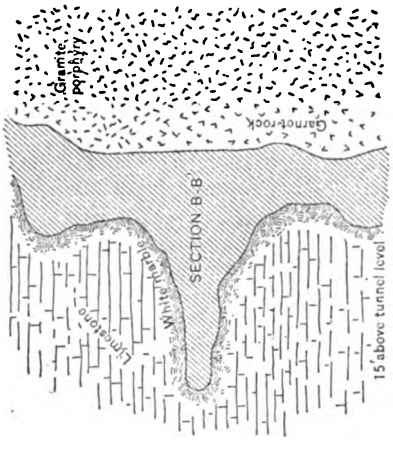

Fig. 9. Plan and sections of Copper Bullion Shoot No. 2, Mackay, Idaho, showing occurrence of ore on the limestone side of a garnet zone.

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ore-bodies occur in the limestone close to or adjoining the granite, but ore also occurs in the granite, "often at considerable distance from the limestone." "The constituent minerals, and general character of the ore-bodies in the two formations, are very similar." The principal copper minerals are bornite and chalcopyrite, which are associated either with magnetite and hematite or with garnet, augite and tremolite. "All the ore-bodies of this (the latter) class, so far discovered, occur in the limestone, close to the granite, and are often separated from the granite by a zone of more or less completely replaced lime-

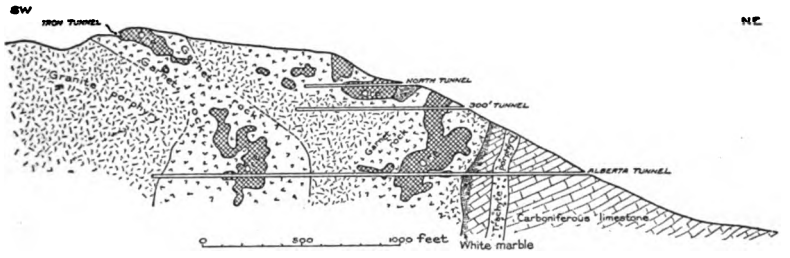

Fig. 10. Section through Alberta Mine, Mackay, Idaho, showing occurrence of ore in the central part of a garnet-diopside mass.

stone."[18] This relationship is clearly brought out by the geologic maps of the Grafter Mine and the Best Chance ore-body. Endomorphism has resulted in a considerable development of garnet, pyroxene and epidote in the granitic mass.

Interpretation

The extent to which the occurrence of ore on the limestone side of garnet zones, as illustrated in the seven well known districts cited above, represents a general law cannot be definitely stated at present. Indeed, the object of this paper is merely to set it forth as a working hypothesis in the hope of arousing discussion and stimulating observation. It is highly probable, however, that there are many more examples of the relationship. In papers on four of the districts cited one writer has clearly stated or illustrated the relationship, but in the writing of another on the same deposit I have been unable to find a quotable statement.

The occurrence of ore on the limestone side of garnet zones, whether it be a constant relationship or not, must be explained for

[18] *Ibid.*, p. 22.

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the several important deposits cited above before knowledge of ore genesis approaches completeness. In the abstract there are two possible explanations; (1) either the sulphides form synchronously at a lower temperature than the lime-silicates and thus occur near the outer margin of metamorphism, or (2) the sulphide-rich solutions are delivered to the contact zone later than those characteristically forming lime-silicates, and replace the limestone in preference to the metamorphic rock earlier developed. Probably most students of the subject will favor the latter view and in stong support of it is the occurrence of apparent feeders at Seven Devils which connect the ore downward across the garnet zone with the quartz diorite. Also in support of this alternative is the broad observation based on mineral paragenesis "that emanation of sulphides and magnetite continues after the contact action, resulting in silicate rock, is completed."[19]

But the alternative explanation must not be too lightly considered. If the sulphides form at lower temperatures than the lime-silicates, their zone of deposition may be expected gradually to draw in toward the source of energy as cooling of the intrusive mass progresses. This implies a superposition of minerals of lower temperature range upon those earlier formed at higher temperatures, providing that their source of supply is not earlier cut off or exhausted. Would not this give the same relations of sulphides to silicates as would a sequential supply of solutions of different type?

It seems to the writer that the explanation of the phenomena requires broader considerations than the paragenetic relations of minerals in the hand specimen, although these have their value. It is generally recognized that the sulphides in part, perhaps in large part, develop contemporaneously with lime-silicates and that most of them occur in small amounts as constituents of igneous rocks. Thus, we would not expect to find a temperature control sufficiently marked to afford the relations observed in the deposits herein cited. The fact that the silicate minerals in most places are more widely distributed along the contact than the ore minerals is also probably significant.[20] But the silicate minerals themselves are localized along the contact in many places and this has been considered as indicating the escape of the solutions through fissures in an outer magma shell.[21] The par-

[19] Lindgren, W., The origin of the "Garnet Zone" and associated ore deposits, Econ. Geol., vol. 9, pp. 283–292, 1914.

[20] Lindgren, W., *loc. cit.*, pp. 285–286.

[21] Butler, B. S., Geology and ore deposits of the San Francisco and adjacent districts, Utah, Prof. Paper, U. S. Geol. Survey, no. 80, p. 12, 1913.

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ticular localization of the sulphide-bearing portions of the contact zones seem to be more rationally explained by solutions of different or gradually changing composition than by temperature control.

Summary and Conclusions

The preference of ore for the limestone side of seven important contact zones has been shown by citations and diagrams, and a desire has been expressed to ascertain through discussion how general this relationship is.

The phenomena may be interpreted as due either to heat control or to a supply of solutions of changing composition such that lime-silicates are predominantly formed during the earlier stages of deposition and the sulphides during the later. The latter view is favored by the writer.

If the relationship should prove to be a constant one it will be of considerable value in the exploitation of contact deposits, for other things being equal, development work will follow the limestone rather than the intrusive side of the garnet zone. Even at present enough is known to recommend that the habit of the individual deposit in this particular be carefully observed as a guide to later search for ore. In the case of engulfed blocks of limestone the limestone-side will in many places be the central part of the garnet mass.

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FAUNA OF THE FERNANDO OF LOS ANGELES

BY
CLARENCE L. MOODY

UNIVERSITY OF CALIFORNIA PRESS
BERKELEY

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Introduction

In the course of excavation work on Fourth Street, Los Angeles, in the fall of 1913, fossil-bearing beds were encountered which have yielded a marine fauna possessing several features that may prove of some importance in the final solution of the problem of late Tertiary history of the southern Coast Ranges of California. Mr. J. Z. Gilbert, of the Los Angeles High School, learned of the discovery of shells by the workmen, and took steps to secure such specimens as were available. Due to his painstaking and systematic

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collecting a fauna of approximately 160 species was obtained. The material, which is in a splendid state of preservation, was entrusted to the University of California for study.

It is with pleasure that the writer acknowledges his indebtedness to Mr. Gilbert for his generosity in providing the abundant material for study, and to Professor J. C. Merriam and Dr. B. L. Clark for co-operation and valuable assistance during the progress of the work. This opportunity is also taken to thank Mrs. Ida Oldroyd for consultation, Dr. Paul Bartsch, Dr. Ralph Arnold and Mr. Homer Hamlin for information which has aided materially in the course of the study, and Professor W. J. Raymond for access to his splendid molluscan collection.

OCCURRENCE

The fauna upon which the following report is based was obtained from a bluish gray clay exposed by excavation for a building site on Fourth Street between Hill Street and Broadway, near the center of the city of Los Angeles. Shells were first found at thirty-four feet from the surface. A communication from Mr. Gilbert states that the clays seemed to dip a few degrees toward the northwest.

In the geologic map of the Los Angeles oil fields accompanying the text of Bulletin 309 of the United States Geological Survey, the locality under consideration is included in the Fernando formation. It is also stated in this bulletin[1] that marine Pleistocene deposits overlie the true Fernando in the region of the oil belt and farther south, especially on the top of the ridge on which the Normal School is situated. As the locality described is now inaccessible, question arises whether the fossils under discussion were obtained from these terrace deposits or from the true Fernando. From a consideration of various phases of the fauna to be discussed later, no hesitation is felt in assigning it to the latter formation.

PREVIOUS KNOWLEDGE OF RELATED OCCURRENCES

Fossils have been known from various localities in Los Angeles since the opening of the oil fields in and around the city. In Bulletin 11 of the California State Mining Bureau, 1896, W. L. Watts[2] gives a list of 34 species obtained from oil wells and from the site of the State Normal School on Fifth Street, which present a faunal facies not different from those obtained from the Fourth Street locality. In

[1] Arnold, R., Bull. U. S. Geol. Surv., no. 309, p. 153, 1907.

[2] Watts, W. L., Bull. Calif. State Min. Bureau, no. 11, pp. 79–81, 1896.

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the collection obtained by Mr. Watts, Dr. J. G. Cooper identified the following species:

Bittium asperum Gabb
Calliostoma costatum Martyn
Cancellaria vetusta Gabb
Cerithidea californica Hald.
Chama exogyra Conr.*
Corbula luteola Cpr.
Crepidula grandis Conr.*
Cryptomya californica Conr.
Cypricardia pedroana Conr.
Diplodonta orbella Gld.
Glycimeris (Axinaea) intermedia Brod.
Kellia suborbicularis Mont.
Lithophagus plumulus Rve.
Macoma inquinata Desh.
Macoma nasuta Conr.
Mangilia (Clathurella) conradiana Gabb*
Mactra (Standella) californica Conr.
Mitra maura Swains.*
Murex (Ocinebra) lurida Midd.*
Nassa californica Conr.*
Nassa fossata Gld.*
Nassa mendica Gld.*
Nassa perpinguis Hds.*
Ostrea vespertina Conr.
Paphia staleyi Gabb
Pecten (Janira) bellus Conr.
Pecten (Hinnites) giganteus Gray*
Pecten pedroanus Trask
Placunanomia, n.sp.
Platyodon cancellatus Conr.
Saxidomus gibbosus Gabb
Semele decisa Conr.
Sinum (Sigaretus) planicostum Gabb

* Species known also in the Fourth Street fauna.

In the above list of species ten forms are found which also occur in the Fourth Street fauna.

During the construction of the Third Street tunnel fossiliferous blue clays were found which yielded several interesting invertebrate species, among which was a giant *Lima* described by Dr. W. H. Dall [3] as *L. hamlini.* Another form which occasioned some confusion for a time was considered by Dr. R. E. C. Stearns[4] to belong to the Rudistae and was described by him as *Radiolites hamlini.* Upon the evidence of this species the deposits underlying Los Angeles were referred to the Cretaceous.[5] Later Dr. T. W. Vaughan expressed the opinion that the flat valve of the supposed *Radiolites* was really an individual coral, while the elongated portion, though still somewhat problematical, is probably to be referred to the Cirripedia.[6]

From a small molluscan fauna in material furnished by Dr. Stearns and Mr. Homer Hamlin, Dr. Dall [7] determined the Third Street tunnel horizon as probably Pliocene, and in 1907 Dr. Ralph Arnold [8] definitely

[3] Dall, W. H., Nautilus, vol. 14, no. 2, pp. 15–16, June, 1900.

[4] Stearns, Dr. R. E. C., Science, n. s. vol. 12, no. 294, pp. 247–250, Aug. 17, 1900.

[5] Vaughan, T. W., Nautilus, vol. 14, no. 2, p. 36, June, 1900.

[6] Dall, W. H., Science, n. s. vol. 15, no. 366, pp. 5–16, Jan. 3, 1902.

[7] Dall, W. H., *op. cit.*

[8] Arnold, R., Proc. U. S. Nat. Mus., vol. 32, p. 527, 1907.

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correlated the Los Angeles clays with the middle Fernando formation. Dr Arnold regards the beds as of lower or middle Pliocene age.[9]

The species upon which this correlation was based are as follows:

Arca multicostata Sby.
Astarte, sp.
Carditoid
Lima hamlini Dall
Macoma, sp. indet.
Nassa hamlini Arnold
Pecten ashleyi Arnold
Pecten latiauritus Conrad
Pecten opuntia Dall
Pecten pedroanus Trask (abundant)
Pecten stearnsii Dall
Buccinum, sp. indet.
Fissuridea murina Cpr.
Neverita recluziana Petit
Pleurotoma, sp. indet.
Priene oregenensis Redf. var. angelensis Arnold

Pecten opuntia, Fissuridea murina and *Neverita recluziana* occur also in the fauna from the Fourth Street locality.

It is believed that the fossils obtained by Mr. Gilbert support this correlation in part, and that in addition to increasing considerably the known fauna of the Fernando, they present the opportunity of making a more exact comparison of the southern Pliocene with that of the Great Valley and of central California.

LIST OF SPECIES

In the succeeding faunal list a rough statement of the frequency value of each species is attempted by an arbitrary division of the fauna into four classes which are enumerated and designated as follows: (1) very abundant; (2) common; (3) uncommon; (4) rare. Forms represented by more than twenty-five individuals have been classed as "very abundant"; those which appear in only one or two individuals are "rare." In the column headed "Geologic Range," R indicates Recent; Pl, Pleistocene; P, Pliocene; M, Miocene. The ranges given are those heretofore recognized.

	Frequency	Geol. Range
RHIZOPODA		
Nodosaria, sp.	4	
ANTHOZOA		
Astrangia insignifica Nomland	4	P
BRYOZOA		
Several species	1	
BRACHIOPODA		
Terebratalia hemphilli(?) Dall	4	P
Laqueus jeffreysi(?) Dall	4	P–R
AMPHINEURA		
Chiton	4	

[9] Arnold, R., Prof. Paper, U. S. Geol. Surv., no. 47, p. 29, 1906.

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GASTROPODA	Frequency	Geol. Range
Acmaea insessa Hinds	4	Pl–R
Acmaea, cf. scabra Nuttall	4	Pl–R
Admete gracilior (Carpenter)	1	P–R
Amalthaea tumens (Carpenter)	4	Pl–R
Amphissa corrugata (Reeve)	1	P–R
Amphissa versicolor Dall	2	Pl–R
Astraea, sp.	4	
Astraea inequale (Martyn)	4	Pl–R
Bela fidicula Gould	2	P–R
Bela sanctaemonicae Arnold	2	Pl
Bittium californicum Dall and Bartsch	2	Pl–R
Bittium rugatum Carpenter	1	P–R
Borsonia inculta, n. sp.	4	P
Calliostoma canaliculatum (Martyn)	3	P–R
Callistoma gemmulatum Carpenter	3	P–R
Calliostoma tricolor Gabb	2	P–R
Calyptraea (Galerus) mammillaris (Broderip)	2	P–R
Calyptraea radians Lamarck	2	P–R
Cancellaria crawfordiana Dall	4	Pl–R
Cancellaria quadrata, n. sp.	4	P
Cerithiopsis tuberculata Carpenter	3	Pl–R
Chrysodomus dirus meridiei, var. nov.	4	P
Chrysodomus rectirostris Carpenter	2	Pl–R
Chrysodomus tabulatus Baird	3	P–R
Columbella californiana Gaskoin	2	Pl–R
Columbella (Astyris) carinata Hinds	1	P–R
Columbella (Astyris) constantia, n. sp.	2	P
Columbella (Astyris) gausapata, Gould	1	P–R
Columbella (Astyris) tuberosa (Carpenter)	1	P–R
Conus californicus Hinds	2	P–R
Crepidula adunca Sowerby	3	P–R
Crepidula dorsata Broderip	4	P–R
Crepidula grandis Middendorf	3	M–R
Crepidula nivea Dall	4	P–R
Crepidula princeps Conrad	1	P–R
Crepidula rugosa Nuttall	1	Pl–R
Cylichna alba Brown	3	Pl–R
Epitonium hindsi (Carpenter)	3	Pl–R
Epitonium indianorum (Carpenter)	3	Pl–R
Epitonium (Opalia) retiporosa (Carpenter)	4	R
Fissuridea murina (Carpenter)	4	P–R
Fusinus barbarensis (Trask)	2	P–R
Fusinus rugosus (Trask)	4	P–R
Haliotis, sp.	4	
Lacuna compacta Carpenter	3	Pl–R
Lacuna porrecta Carpenter	3	Pl–R
Lacuna solidula Carpenter	3	Pl–R
Leptothyra carpenteri Pilsbry	3	Pl–R
Leptothyra paucicostata Dall	3	Pl–R
Mangilia angulata Carpenter	3	P–R

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Gastropoda—(*Continued*)	Frequency	Geol. Range
Mangilia (Clathurella) conradiana (Gabb)	1	P–R
Mangilia hexagona Gabb	4	Pl–R
Mangilia muricidea, n. sp.	4	P
Mangilia oldroydi Arnold	4	Pl
Mitra maura Swainson	4	P–R
Murex interfossa (Carpenter)	2	P–R
Murex lurida (Middendorf)	2	Pl–R
Murex peritus (Hinds)	2	Pl–R
Murex, sp.	3	
Nassa cooperi Forbes	3	P–R
Nassa insculpta Carpenter	2	Pl–R
Nassa mendica Gould	1	P–R
Nassa perpinguis Hinds	1	M–R
Natica (Cryptonatica) clausa Broderip and Sowerby	2	Pl–R
Natica (Euspira) orbicularis Nomland	2	P
Natica (Neverita) recluziana Petit	2	M–R
Odostomia, sp. A	4	R
Odostomia, sp. B		
Odostomia gravida Gould	4	Pl–R
Odostomia satura Carpenter	4	R
Olivella intorta Carpenter	3	P–R
Purpura foliata Martyn	4	Pl–R
Priene oregonensis (Redfield)	3	P–R
Rissoa acutilirata Carpenter	1	P–R
Seila assimilata (C. B. Adams)	3	Pl–R
Serpulorbis squamigerous (Carpenter)	2	Pl–R
Siphonalia gilberti, n.sp.	4	P
Siphonaria, sp.	4	
Tornatina cerealis Gould	3	Pl–R
Tornatina culcitella Gould	3	Pl–R
Triphoris adversa Montagu	3	Pl–R
Tritonofusus, sp.		
Trophon (Boreotrophon) raymondi Dall, n.sp.	2	P
Trophon (Boreotrophon) gracilis Perry	4	P–R
Trophon (Boreotrophon) stuarti, var. praecursor Arnold	3	P–Pl
Turbonilla, sp. A	4	Pl–R
Turbonilla, sp. B		
Turbonilla tridentata (Carpenter)	4	Pl–R
Turris (Drillia) modestus, n.sp.	4	P
Turris (Drillia) mercedensis (B. Martin)	3	P
Turris perversa (Gabb)	1	P–R
Turris (Drillia) renaudi (Arnold)	3	P–Pl
Turris (Bathytoma) tryoniana (Gabb)	4	P–R
Turris (Drilla) inermis(?) (Hinds)	4	P–R
Turritella cooperi Carpenter	1	P–R
Turritella jewetti Carpenter	1	P–Pl
Volutharpa, sp.	4	
Scaphopoda		
Cadulus nitentor Carpenter	1	Pl–R
Dentalium hexagonum Dall	3	P–R

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PELECYPODA	Frequency	Geol. Range
Anomia lampe Gray	4	Pl–R
Arca, sp.	4	
Cardium corbis Martyn	3	P–R
Chama exogyra Conrad	2	Pl–R
Chione simillima (Sowerby)	4	Pl–R
Chione, sp.	4	
Corbula tenuis, n.sp.	4	P
Glycimeris, cf. septentrionalis Middendorf	4	P–R
Leda hamata Carpenter	1	P–R
Leda tephria Dall	1	P–R
Lyonsia californica Conrad	3	P–R
Macoma calcarea Gmelin	2	P–R
Macrocallista densa, n.sp.	3	P
Marcia subdiaphana (Carpenter)	4	P–R
Modiolus, sp.	4	
Monia macroschisma (Deshayes)	3	M–R
Mytilus edulis Linne	4	M–R
Panope generosa (Gould)	4	P–R
Panomya ampla Dall	4	P–R
Pecten (Propeamusium) levis, n.sp.	4	P
Pecten (Pecten) hemphilli Dall	4	P
Pecten (Patinopecten) caurinus Gould	3	P–R
Pecten (Hinnites) giganteus (Gray)	3	P–R
Pecten (Chlamys) hastatus Sowerby	2	P–R
Pecten (Patinopecten) healeyi Arnold	3	P
Pecten (Chlamys) hericeus Gould	2	P–R
Pecten (Chlamys) opuntia Dall	3	P
Pecten, sp.	4	
Petricola carditoides Conrad	3	Pl–R
Petricola lamellifera (Conrad)	3	Pl–R
Phacoides californicus (Conrad)	3	P–R
Phacoides, cf. annulatus (Reeve)	4	P–R
Phacoides tenuisculpta (Carpenter)	1	P–R
Pholadidea penita Conrad	4	P–R
Protocardia centifilosa Carpenter	4	P–R
Psephis tantilla Gould	1	Pl–R
Saxidomus nuttalli Conrad	4	P–R
Siliqua lucida Conrad	4	Pl–R
Solen sicarius Gould	2	M–R
Spisula catilliformis (Conrad)	4	P–R
Tellina, sp.	3	
Thracia trapezoides Conrad	4	M–P
Thyasira gouldi Phillippi	4	Pl–R
Tivela stultorum Mawe	4	Pl–R
Venericardia barbarensis Stearns	1	P–R
Venericardia borealis Gould	1	P–R
Yoldia scissurata Dall	4	P–R
ECHINOIDEA		
Strongylocentrotus franciscanus A. Agassiz	1	Pl–R
Strongylocentrotus purpuratus Stimpson	1	Pl–R

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	Frequency	Geol. Range
CRUSTACEA		
Cancer, sp.	1	
VERTEBRATA		
Indeterminable tooth	4	

Note: Several new species of the Pyramidellidae, found in the fauna, are being described by Dr. Bartsch.

FAUNAL SUMMARY

Total number of species	157
Total number of molluscan species	147
Gastropoda	97
Pelecypoda	47
Scaphopoda	2
Amphineura	1
Total number of molluscan species named	131
Number of extinct molluscan species	22
Percentage of extinct molluscan species	16.7
Number of molluscan species confined to northern waters	19
Percentage of living fauna confined to northern waters	16.4

GENERAL FEATURES OF THE FAUNA

Aside from the new species described, some uncommon forms have been identified from the new locality. A single individual coral was found embedded in clay well within a large *Natica* shell. The species has been described by J. O. Nomland [10] as *Astrangia insignifica.* The genus *Haliotis* is represented by two indeterminate individuals. *H. lomaensis* has been described by Anderson[11] from the Cretaceous of Point Loma, but the abalone does not again appear until Pliocene time.[12] Good specimens have also been obtained recently from the San Diego Pliocene.

One of the striking features of the fauna is the unusually large number of species of *Crepidula.* Of these *C. rugosa* and *C. princeps* are represented by a great number of individuals. The latter species, remarkable for its large size, is extremely abundant, but singularly enough, save for one specimen labeled "Signal Hill," in the collection of Stanford University, is unknown from the San Pedro formations, although it is listed from this vicinity by Blake in the Geodetic Survey Report for 1855.

[10] Nomland, J. O., Univ. Calif. Publ., Bull. Dept. Geol., vol. 9, no. 5, p. 65, 1916.

[11] Anderson, F. M., Proc. Calif. Acad. Sci., 3d Series, vol. 2, no. 1, p. 75, 1902.

[12] Arnold, R., Mem. Calif. Acad. Sci., vol. 3, pp. 33–34, 1903.

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Epitonium retiporosa Carpenter for the first time takes its place in a fossil faunal list. *Murex* (*Ocinebra*) *peritus* Hinds, *Cancellaria crawfordiana* Dall and *Admete gracilior* Carpenter, uncommon as fossils, appear in splendidly preserved individuals. No less than fifteen members of the Turritidae are present, of which *Turris perversa* Gabb occurs in the greatest abundance. Other gastropods which are exceedingly abundant are *Turritella cooperi* Carpenter, *T. jewetti* Carpenter, *Columbella carinata* Hinds, and *Psephis tantilla* Gould.

Several species are of interest in their bearing on the correlation of the clay deposits with known horizons in the standard Coast Range section. Of these the pectens are of great importance; nine species appear in the fauna, eight of which have been identified. Three of the recognized species—*Pecten healeyi* Arnold, *Pecten hemphilli* Dall, and *Pecten opuntia* Dall—are believed to be confined to the Pliocene. An additional form not known to occur above the Pliocene is *Thracia trapezoides* Conrad. Of especial correlative value is the discovery in the Los Angeles material of *Turris* (*Drillia*) *mercedensis* Martin[13] and of *Natica orbicularis* Nomland,[14] two recently described Pliocene species, the former from the Merced of northern California, and the latter from the Etchegoin of the southern San Joaquin Valley.

An anomalous feature of a fauna bearing several restricted Pliocene forms is the appearance of *Strongylocentrotus* in some abundance; spines and fragments of the test of both the West Coast species of this living echinoid are quite common. *Strongylocentrotus* has been reported from the San Diego beds by Arnold[15] and spines referable to this genus, associated with *Pecten healeyi* and *Epitonium varicostata,* occur in material collected there by Dr. E. L. Packard. Thus the close similarity between the Pliocene fauna of San Diego and the Los Angeles fauna is emphasized.

After a study of the bathymetric range of each species it appears that the fauna lived in comparatively shallow water. Of the 114 living species, nineteen are now confined to waters considerably north of the latitude of Los Angeles, although some of them have been dredged from deep water south of the Channel Islands. None of the species, with the possible exception of a small indeterminable *Arca,* can be regarded as typically southern forms. Thus the present geo-

[13] Martin, B., Univ. Calif. Publ., Bull. Dept. Geol., vol. 8, no. 7, p. 194, 1915.

[14] Nomland, J. O., Univ. Calif. Publ., Bull. Dept. Geol., vol. 9, no. 14, p. 65, 1916.

[15] Arnold, R., U. S. Geol. Surv. Prof. Paper, no. 47, p. 28, 1906.

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graphic range of the Recent species gives the fauna a boreal aspect. This evidence may be taken to support the view that the climatic environment of the Los Angeles fauna was quite similar to that of the San Pedro Pliocene fauna, the boreal character of which is equally pronounced, and in which a near-shore character is indicated by the lithology of the enclosing beds.

COMPARISON WITH RELATED FAUNAS

It is obvious that the Los Angeles fauna must be referred either to the lower Pleistocene or to the upper Pliocene. Before a more definite correlation can be made it is necessary to compare percentages and individual species with related faunas of recognized stratigraphic position. Faunas with which relationships might be anticipated are those derived from the Etchegoin, Merced, upper, middle and lower Fernando, San Diego and San Pedro formations.

Revised faunal lists[16] from various horizons in the Etchegoin formation of the Southern San Joaquin area show that only eighteen species of that formation are found in the Los Angeles fauna, and these are for the most part such long-range forms as *Natica recluziana* and *Panope generosa*. Three supposedly restricted Pliocene species, *Natica orbicularis, Turris mercedensis* and *Pecten healeyi,* which are found at the Los Angeles locality, occur in higher horizons of the Etchegoin, and may indicate contemporaneity of later phases of that period of deposition with the Los Angeles clays. In the main, however, the Etchegoin fauna is decidedly earlier than that of the latter formation. Recent work has shown that the percentage of extinct species in the fauna of the upper Etchegoin is between 58 and 60, while this figure for the Los Angeles beds is 16.7.

Several points of resemblance appear between the Los Angeles fauna and the faunas of the Merced and Purisima formations of middle and northern California. The latter faunas, which for the purposes of this paper may be considered collectively, are typically boreal. Northern types of pectens and mactras abound; *Natica clausa* and *Macoma calcarea* occur in many horizons, but the feature which stamps the central California Pliocene fauna as incontestably boreal, is the great abundance, both specifically and individually, of the Buccinidae. This family is much less prominently developed in the southern fauna, but is still sufficiently well represented to show an important similarity between the two faunas. The upper Merced of the type locality of

[16] Nomland, J. O., Mss. in press.

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Seven-Mile Beach is now generally conceded to belong to the Pleistocene; Martin[17] lists twenty-three species from this horizon, all of which are living. From the lower Merced 106 species have been obtained, of which fifty-seven, or 53.7 per cent, are extinct. The restricted Pliocene forms common to the two faunas are *Turris mercedensis, Thracia trapezoides,* and *Pecten healeyi,* which has so far been reported only from the Purisima. It thus appears that the main body of the Merced antedates the Los Angeles deposit, and that the latter formation is the time equivalent of only the later horizons of the central California Pliocene.

The Fernando formation, which includes most of the marine Pliocene deposits of southern California, is, in the Santa Clara Valley, divided by Eldridge and Arnold[18] into three faunal horizons. The lowest horizon is considered as approximately equivalent to the Etchegoin, the middle is probably the correlative of the Purisima and the lower part of the San Diego formation, while the upper is well within the Pleistocene, the higher horizons being correlated with the upper San Pedro. The fauna of the lower Fernando, as listed by Arnold, contains twenty-nine determined species, of which 55 per cent are extinct; thirty-one species are reported from the middle division, with 45 per cent extinct; from the upper division fifty-one species are named, only 12 per cent of which are extinct. From a consideration of percentages alone the Los Angeles fauna would unhesitatingly be placed near the fauna of the upper Fernando; but, as the Los Angeles fauna is nearly three times the size of the latter, perhaps a more significant feature is the number of restricted Pliocene species which appear from the two formations. In the lower Fernando thirteen restricted species are reported, none of which are found in the Los Angeles material. The middle Fernando contains twelve Pliocene forms, with *Pecten healeyi* alone common to two faunas. No characteristic Pliocene forms occur in the upper division. The majority of the species here classed as "restricted" in the middle and lower Fernando are new; the only Pliocene form that enjoys even a moderate geographic range is the above-mentioned pecten. On this basis, including the *Astrangia* described by Nomland and the ten species described in this paper, seventeen restricted Pliocene forms occur in the new fauna; its affinities are thus with the middle and lower divisions of the

[17] Martin, B., Univ. Calif. Publ., Bull. Dept. Geol., vol. 9, no. 15, 1916.

[18] Eldridge, G. H., and Arnold, R., U. S. Geol. Surv. Bull. no. 309, pp. 23–28, 1907.

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Fernando. However, the recent work of English[19] shows that the lower Fernando represents a horizon well down in the Pliocene; the Los Angeles fauna is therefore probably to be regarded as the time-equivalent of only the later phases of the middle Fernando.

The fauna of the San Diego formation, which has been so thoroughly studied by Dall [20] at the type locality, and by Arnold [21] at San Pedro, is in many respects more like that from Los Angeles than any of those previously mentioned. Reference has already been made to the boreal character of the two faunas. The San Diego formation at San Pedro has yielded Arnold eighty-four molluscan species, eighty-three of which are determined specifically. Through a typographical error *Fusinus* (*Fusus*) *barbarensis* and *Mangilia* (*Clathurella*) *conradiana* are listed in his report[22] as extinct; with this correction (which is made in the faunal list in Professional Paper No. 47, of the U. S. Geological Survey) twelve species (14.4 per cent) are extinct. *Thracia trapezoides* is the only one of the three restricted Pliocene forms of this locality which occurs in the Los Angeles fauna; at San Diego *Pecten opuntia* and *P. healeyi* occur in addition to this species. The San Diego formation at the type locality is believed by Arnold to include the San Pedro horizon but to extend somewhat lower in the Pliocene.[23] The pectens seem to indicate that the Los Angeles fauna, while probably the correlative of the lower San Diego, is somewhat older than the San Pedro Pliocene. The slightly greater percentage of extinct species and the occurrence of *Natica orbicularis* and *Turris mercedensis* in the former may indicate that the Los Angeles horizon belongs even somewhat below the typical San Diego.

It is the belief of the writer that the fauna obtained from the Los Angeles clays represents the later phases of the middle Fernando. It is probably somewhat older than the San Pedro deposit, but is the equivalent in time of the lower horizons of the San Diego formation.

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[19] English, W. A., Univ. Calif. Publ., Bull. Dept. Geol., vol. 8, no. 8, 1914.

[20] Dall, W. H., Proc. U. S. Nat. Mus., vol. I, 1878, pp. 10–16, pp. 26–30; Proc. Calif. Acad. Sci., vol. 5, 1873, pp. 296–299.

[21] Arnold, R., Mem. Calif. Acad. Sci., vol. 3, 1903; U. S. Geol. Surv. Prof. Paper, no. 47, 1907.

[22] Arnold, R., Mem. Cal. Acad. Sci., vol. 3, p. 15, 1903.

[23] Arnold, R., Mem. Cal. Acad. Sci., vol. 3, p. 13, 1903 (correlation table); U. S. Geol. Surv. Prof. Paper, no. 47, 1907.

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Description of Species

EPITONIUM (OPALIA) RETIPOROSA Carpenter

Plate 1, Figure 3

Opalia retiporosa Cpr., Brit. Assn. Rept., p. 146, 1863

Shell small, elongate, thick; spire greatly elevated. Including the nucleus there are ten rounded whorls ornamented with fourteen irregular, rounded varices. Numerous fine, equally developed spiral and transverse ribs intersect at right angles forming a pronounced though minutely reticulated structure over the entire surface; deep holes occur between the two systems of sculpture; the transverse ribs pass obliquely over the varices. Suture depressed, distinct. Aperture oval; the nacreous layer is slightly reflexed over the large mouth-varix.

Dimensions: longitude, 9.2 mm.; latitude, 3.4 mm.

So far as known this is the first time that this species has been reported as a fossil. The original description of the shell is very brief, and, as the single individual found in this deposit is a perfect specimen, it has been thought well to redescribe and figure it.

SIPHONALIA GILBERTI, n.sp.

Plate 1, Figures 5*a*, 5*b*

Univ. Calif. Coll. Invert. Palaeont., no. 11077. Type locality, Fourth and Broadway, Los Angeles.

Shell fusiform with highly elevated spire. The four or five spiral whorls are ventricose, and distinctly angulated above the middle, with the angle bearing nine or ten rounded nodes which are faint on the body-whorl but strongly and sharply marked on the succeeding whorls; these nodes die out rapidly above and below the angle; below the angulation on the spiral whorls the walls are vertical; region between the angle and the upper suture excavated, producing a collar-like effect. Three systems of spiral sculpture ornament each of the whorls; one unit of sculpture consists of two subquadrate ribs about 1.2 mm. wide and separated by an interspace 3.9 mm. wide; medially between these ribs is a much less prominent rib about 0.8 mm. wide, and flanking it are two yet smaller ones separated from it by deep, rectangular grooves and from the main rib by less pronounced grooves. On the body-whorl there are seven units of the major sculpture below and one on the angle, while six ribs of equal strength mark the excavated region between the angle and the suture. Primary and

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medial ribs reflected interiorly on the outer lip by ridges and grooves. Shell longitudinally sculptured only by numerous fine incremental lines. Aperture oval, although somewhat constricted toward the canal-end; sutural notch deep; outer lip thin; inner lip smooth, and fairly heavily incrusted. Umbilicus excavated, but imperforate; columella light and straight; canal short and pronouncedly recurved.

Dimensions.—Longitude, 78 mm.; latitude, 47.3 mm.

This species agrees in its broad features with *Thais kettlemanensis* Arnold described from the Jacalitos, but is readily distinguished by the greater height of spire, more acute apical angle, greater inclination of the spiral sculpture to the columellar axis, deeper sutural notch, sharper recurving of the canal and by the pronounced rounding groove above the sharp angle. It is quite distinct in outline and sculpture from the recent *Siphonalia kelletti*, but its aperture and canal characters place it in the same genus.

Two reasonably well preserved specimens were found.

CHRYSODOMUS DIRUS MERIDIEI, var. nov.

Plate 1, Figures 9*a*, 9*b*

Univ. Calif. Coll. Invert. Palaeont., no. 11078. Type locality, Fourth and Broadway, Los Angeles.

Shell medium-sized, short, fusiform. The elevated spire is made up of six or seven rounded whorls ornamented with about ten transverse rounding nodes which die out toward the sutures and are nearly obsolete on the body-whorl. The body-whorl possesses a tendency toward tabulation due to a faint angulation in the middle portion of its upper half. The shell is ornamented by seventeen strong, squarish, equally spaced ribs, the interspaces being three-fourths the width of the rib. The suture is strongly appressed and, due to the enlargement of the last spiral rib and to the excavated subsutural area, appears to bear a collar. Aperture subquadrate; inner lip incrusted; outer lip heavily thickened; umbilicus imperforate; canal short and strongly recurved.

Dimensions.—Longitude, 44.1 mm.; latitude, 21.6 mm.

Comparison with *C. dirus* shows that, while probably belonging to the same species, this form possesses characters sufficiently marked to give distinction to the variety. Among the more important differences are the presence of the angulation, the sharply curved canal, and the heavy thickening of the outer lip of the Los Angeles form. The

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ribbing is found to be heavier on the variety; and further only seventeen spiral ribs occur on it, while from twenty to twenty-two appear on each of the specimens of *C. dirus* in the University of California museum collection.

Only one individual was found.

TROPHON RAYMONDI, n.sp.

Plate 1, Figures 1*a*, 1*b*

Univ. Calif. Coll. Invert. Palaeont., no. 11088. Type locality, Fourth and Broadway, Los Angeles.

Shell small, enlongate, fusiform; spire consists of four tabulated whorls with cylindrical walls, each bearing about twelve pointed spinous nodes which project above the prominent angulation, but die out rapidly below in the faint transverse ridges which alone ornament the whorls. Body-whorl ventricose, enlongate, bearing fourteen sharp nodes which increase in size and elevation above the tabulation toward the peristome; no spiral sculpture; transverse ornamentation consists merely of coarse incremental lines. Aperture enlongate; outer lip thick, slightly reflexed; inner lip smooth, not incrusted; columella long, straight; canal long, straight, narrow.

Dimensions.—Longitude, 14.0 mm.; latitude, 5.0 mm.

The long straight canal, sharp nodes, and unadorned whorls of this form seem unique characters which readily permit its separation from other members of this genus on the coast.

At least eighteen well preserved specimens were obtained which show great variation in size, the dimensions given being those of an average specimen.

COLUMBELLA (ASTYRIS) CONSTANTIA, n.sp.

Plate 1, Figures 7*a*, 7*b*

Univ. Calif. Coll. Invert. Palaeont., no. 11079. Type locality, Fourth and Broadway, Los Angeles.

Shell small, light, rather thick; apex acute, with seven slightly rounded whorls. The body-whorl bears an indistinct angulation below the center, but except for very fine incremental lines the whorls are otherwise unadorned. The suture is distinctly appressed. The columella is recurved and striated inside and outside with from nine to twelve spiral ridges which rapidly die out as the body-whorl enlarges from the pillar. Aperture elliptical; inner lip smooth and not incrusted; outer lip thin, without crenulations. The canal is long, narrow and recurved.

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Dimensions.—Longitude, 8 mm.; latitude, 3.6 mm.

The number of whorls and the enlongate, narrow canal serve to distinguish this species from its nearest relative, *C. gausapata,* which also occurs in some abundance in the material. Crenulations on the outer lip are absent in all the specimens, hence some doubt is entertained in placing the form in the subgenus *Astyris.*

A dozen or more individuals were found, several of which are perfectly preserved. Many of the shells show a fine polish.

TURRIS (DRILLA) MODESTUS, n.sp.,

Plate 1, Figure 8

Univ. Calif. Coll. Invert. Palaeont., no. 11080. Type locality, Fourth and Broadway, Los Angeles.

Shell very small, conical, turreted, with elevated spire; lateral outline very slightly concave. There are seven conical whorls, each bearing near the base a faint double angulation determined by two heavy spiral ribs which appear nodose from the intersection of an equally developed set of transverse ribs. The body-whorl is ornamented with twelve distinct but not prominent spiral ribs below the lower angulation and extending well out on the canal; two ribs of intermediate prominence appear above the upper angulation; the transverse sculpture consists of sixteen equidistant, equally developed, slightly obliquely directed longitudinal ribs, which are obsolete on the last three spiral whorls. The suture is rather conspicuously depressed. Aperture elliptical; outer lip unknown; inner lip incrusted, smooth. The canal is of moderate length, narrow and slightly recurved.

Dimensions.—Longitude, 5.2 mm.; latitude, 1.9 mm.; apical angle, 20 degrees.

The size, shape and ornamentation of this species serve to separate it from other known members of the Turritidae.

One specimen only was found, from which the peristome had unfortunately been broken.

BORSONIA INCULTA, n.sp.

Plate 1, Figures 2*a*, 2*b*

Univ. Calif. Coll. Invert. Palaeont., no. 11081. Type locality, Fourth and Broadway, Los Angeles.

Shell small, turreted, broadly fusiform, with a moderately elevated spire. Six whorls appear, each bearing a double angulation of which

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the superior one is the more strongly marked. Suture well defined by a strongly depressed line which is partially covered by a somewhat obscure collar projecting from the whorl below. The interangulation portions of the whorls have parallel walls, and this feature, together with the low pitch of the spire, gives a subquadrate appearance to each whorl. Ornamentation of the body-whorl consists of two very faint revolving ribs above the upper angulation, and three somewhat more pronounced ones below the lower angulation; transverse sculpture limited to very numerous, fine incremental lines, which are convexly reflexed posteriorly at the upper angulation, forming a broad turritoid embayment at this point. Aperture elongated and somewhat rectangular, with prominent sutural notch at top. Outer lip thin; inner lip smooth, and lightly incrusted. The canal is deep, short and recurved.

Dimensions.—Longitude, 13.5 mm.; latitude, 6.9 mm.

The short canal and low pitch of the spire serve to distinguish this form from related species. The type specimen presents a very rough, uncouth appearance due in part to erosion, in part to unequal development of the lines of growth, but largely to attack from parasitic or marauding neighbors.

One specimen was found in the material available.

MANGILIA MURICIDEA, n.sp.

Plate 1, Figures 10*a*, 10*b*

Univ. Calif. Coll. Invert. Palaeont., no. 11082. Type locality, Fourth and Broadway, Los Angeles.

Shell very small, elongate, fusiform, with an elevated spire. The six convex whorls are ornamented with very coarse, reticulating ribs; each whorl bears two very strongly marked spiral ribs which produce a faint double angulation; two ribs of lesser weight appear above the central ribs and four below; the interspaces between both major and minor ribs contain small inter-ribs on the body-whorl. The longitudinal sculpture consists of fourteen prominent, slightly obliquely directed ribs with quite narrow interspaces. The intersection of the two systems of ornamentation produces a nodose effect. The suture is strongly depressed. The ovate aperture bears an obscure sutural notch; outer lip unknown, inner lip smooth. The canal is long, broadly tapering, and nearly or quite straight.

Dimensions.—Longitude, 7 mm.; latitude, 2.9 mm.

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The coarse sculpture of this species, which resembles that of many of the Muricidae, is believed to differentiate it from other members of the genus.

One specimen only was found, from which the outer lip had been broken.

CANCELLARIA QUADRATA, n.sp.

Plate 1, Figure 6

Univ. Calif. Coll. Invert. Palaeont., no. 11083. Type locality, Fourth and Broadway, Los Angeles.

Shell small, low, fusiform, with a moderately elevated spire, which is perhaps one-fourth the length of the shell. There are six angulated, strongly tabulated whorls, with parallel walls. Sculpture of the body-whorl consists of four equally developed, equidistant spiral ribs below the tabulation, with smaller, low, rounding ribs in the interspaces, and four indistinct ones on the tabulation; ten prominent longitudinal ridges intersect the spiral sculpture at right angles and exhibit a tendency toward the development of spinous nodes on the angulation. Aperture oval, constricted anteriorly; outer lip is unknown; inner lip bears eight spiral lines concentric with the two sharp columellar plications. The pillar is strongly curved away from the aperture; canal broad and probably short.

Dimensions.—Longitude unknown; latitude, 7.5 mm.

The tabulation of the whorls, character of the sculpture and sharpness of the columellar plaits are unique features of this form.

One specimen only was found; a large part of the body-whorl and the canal are lacking.

PECTEN (PROPEAMUSIUM) LEVIS, n.sp.

Plate 2, Figures 2*a*, 2*b*, 2*c*, 2*d*

Univ. Calif. Coll. Invert. Palaeont., no. 11084. Type locality, Fourth and Broadway, Los Angeles.

Shell small, thin, translucent, nearly circular in outline, equilateral, compressed, slightly inequivalve. Right valve is smooth except for numerous very fine incremental lines, which occasionally are enlarged and roughened; traces of submiscroscopic radiating striae are to be seen. Hinge line is about five-eighths the width of the shell; ears sharply set off from the disc by equal impressed lines which are nearly straight and slope evenly from the umbone; anterior ear arcuate, coarsely sculptured by about fourteen subequal ridges which radiate

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from the beak, and by about thirty-five prominent, regular, imbricating lines of growth which curve outward, following the anterior margin; posterior margin makes a right angle with the hinge-line; byssal notch almost obsolete; posterior ear ornamented with a similar number of incremental laminae which are only slightly curved and are nearly vertical, the radiating ridges being indistinct. Interior surface of the valve marked by twenty-two rounding ridges which radiate from the apex but are partially obscured in the upper portions by a callus growth which covers one-third the area of the disc; a single adductor scar appears on the anterior dorsal margin of the callus. Left valve slightly less convex than the right; externally sculptured by fourteen prominent, smooth, rounded ribs which radiate from the apex; in the interspace appear one or sometimes two inter-ribs of varying length, which never reach the beak; anterior ribs and inter-ribs slightly imbricated; incremental lines quite fine and uniform on the posterior three-fourths of the surface. Ears of the left valve subequal; both slightly arcuate below the hinge line, the anterior more coarsely sculptured by twelve radiating striae and thirty or more roughened incremental lines which are vertical on the hinge-line and broadly recurved below; beak sharp and straight and slightly raised above the hinge-line. Interiorly the valve is sculptured by about twenty distinct, rounded ribs radiating from the umbone, which are independent of the external ornamentation and do not reach the ventral margin; internal ribs slightly obscured, as in the right valve, by a callus growth.

Dimensions.—Latitude, 16 mm.; longitudinal diameter, 15.6 mm.

This little pecten is one of four members of the subgenus *Propeamusium* known from the West Coast. *P. davidsoni* and *P. alaskensis* are living forms now inhabiting deep waters from Vancouver Island to Bering Sea; the latter species is said to occur as far south as Panama Bay, and is known from Pleistocene deposits on Vancouver Island and in southern Alaska. *Pecten riversi* Arnold is a closely related form from the Santa Monica Cañon Pliocene. From the description of *P. riversi* it appears that one of the chief characters of the species is the retarded development of the internal lirae, which do not appear until the shell has attained an altitude of 15 mm. In *P. levis* these internal riblets persist to the apex, a character of *P. alaskensis*. Other characters which serve to distinguish this species from *P. riversi* are the smooth incremental lines on the otherwise unadorned surface of the right valve, the lack of imbrication on the ribs of the left valve, and in this valve, the failure of

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the internal riblets to reach the periphery. The external sculpture of the left valve and the outline and submicroscopic radiating striae of the right, described in the new species, are characters quite distinct from *P. alaskensis*.

Four specimens were found, of which two are nearly perfect left valves, and of the two right valves, one is nearly intact.

MACROCALLISTA DENSA, n.sp.

Plate 2, Figures 1*a*, 1*b*

Univ. Calif. Coll. Invert. Palaeont., no. 11086. Type locality, Fourth and Broadway, Los Angeles.

Shell small, thick, broadly subovate, inequilateral, moderately convex. The prosogyrous beaks are moderately elevated. Surfaces of both valves marked by fine incremental lines which occasionally are somewhat enlarged and roughened. Anterior and posterior ends evenly rounded, but as the posterior is somewhat the broader, the shell appears subtruncate. Posterior dorsal margin straight fom the umbo to one-half the distance to the posterior end; ventral margin smooth and thick. No escutcheon appears, and the lunule is very faintly marked by a circumscribing line. Three prominent cardinal teeth appear in each valve, the posterior being longer and narrower than the other two and strongly bifid in each valve. In the right valve are two prominent anterior claspers while a corresponding lateral appears in the left; the ventral lateral in the right valve is in alignment with the anterior cardinal, which is shortened. The nymph plate is smooth and, in the right valve, is elevated at some distance posterior to the last cardinal. The external ligamental groove is long and relatively broad. In the right valve the hinge plate bears a rounding embayment; in the left it is triangular. Pedal scars indistinct; pallial line distant from the ventral margin; pallial sinus capacious and broadly rounding.

Dimensions.—Altitude, 7.4 mm.; diameter, 8 mm.

This beautiful little shell possesses unique characters in the placing of the anterior laterals and in having both posterior cardinals bifid. No near relatives of the form appear in the California Tertiary.

Four specimens were found, of which one is a right valve slightly broken.

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CORBULA TENUIS, n.sp.

Plate 2, Figures 4*a*, 4*b*

Univ. Calif. Coll. Invert. Palaeont., no. 11087. Type locality, Fourth and Broadway, Los Angeles.

Shell small, triangular, very thin, with prominent subcentral prosogyrous beaks which are strongly incurved. Anterior end elongated and evenly rounded; posterior end rounded, but the posterior portion of the shell possesses a posteriorly directed keel passing from the umbo obliquely to the ventral margin which sets off the posterior one-fourth of the shell from the remainder, and makes a small angle within the posterior margin. A few indistinct lines, radiating from the beak, are seen on this posterior one-fourth of the shell; the remaining portion is smooth, except for very fine incremental lines. In the right valve appears one prominent cardinal tooth anterior to the small cartilage-pit; the anterior dorsal margin is produced into a sharp lamellar plate. The anterior adductor scar is elongate, but the posterior is unknown; pedal scar distinct, situated above the adductor. The left valve is unknown.

Dimensions.—Altitude, 7.8 mm.; diameter, 8.6 mm.

The extreme delicacy of shell in this species is one of its most distinctive features. The outline, while rather imperfectly shown in the figures, is also quite distinct from that of any known *Corbula*.

Two rather imperfect right valves were found.

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EXPLANATION OF PLATE 2

Fig. 1*a*. *Macrocallista densa*, n.sp. Internal view of right valve. ×2.
Fig. 1*b*. *Macrocallista densa*, n.sp. External view of right valve. ×2.
Fig. 2*a*. *Pecten levis*, n.sp. External view of right valve. ×2.
Fig. 2*b*. *Pecten levis*, n.sp. Internal view of right valve. ×2.
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Fig. 7*b*. *Turris mercedensis* (Martin), front view. ×2.

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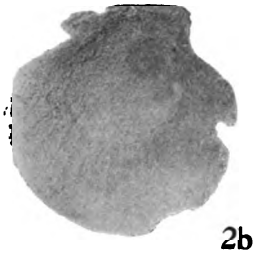

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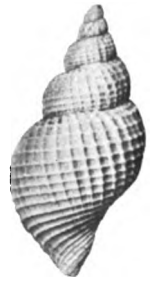

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BULLETIN OF THE DEPARTMENT OF
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Vol. 10, No. 5, pp. 63-73, 5 text-figures Issued November 6, 1916

NOTES ON THE MARINE TRIASSIC REPTILE FAUNA OF SPITZBERGEN

BY
CARL WIMAN

UNIVERSITY OF CALIFORNIA PRESS
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INTRODUCTION

It gives me great pleasure to comply with a request from two American colleagues to make a comparison between the marine Triassic reptiles of Spitzbergen and Europe on the one hand and western North America on the other, and I do this so much the more because on both sides a good deal has come to light since I treated the Triassic ichthyosaurs from Spitzbergen in 1910.[20*] Of reptiles, however, very little material has been added from the Trias of Spitzbergen since the saurian expedition in 1909. The expeditions of 1912 and 1913 have, like the one that is now in progress, been directed chiefly to the somewhat older fish horizon with stegocephalians and fishes.

OCCURRENCE

Not very long ago the ichthyosaurians from the Trias belonged to the greatest rarities; now, on the contrary, they seem to be about

* For literature references see bibliography forming the last division of this paper.
Owing to uncertainty of transport during the past year it has not been possible for the author to read the proof of this paper.—EDITOR.

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equally rich in species, and at least in the northern hemisphere as widely distributed, as during the Jurassic. One knows of finds at a number of places in Germany, Switzerland, Italy, Austria, Roumania,[19] England, Spitzbergen, arctic and western North America, and possibly New Zealand. Among these many finds there are, however, only a few that have given any, palæontologically, more enlightening material. The richest and most important have been the finds in the Daonella limestone, in the West Humboldt Range in Nevada, of Middle Triassic age; and in California, in the Hosselkus limestone, of Keuper age.[10]

The occurrence in northern Italy and Switzerland, just southeast of the southern extremity of Lake Lugano, generally known under the name of Besano, has been productive since the fourth decade of the nineteenth century, and was, though hardly yet fully appreciated, for a long time the only source of knowledge regarding the structure of the Triassic ichthyosaurians. These occurrences belong to a lower horizon of Keuper, Raibl-St. Cassian.[1]

The German occurrences have hitherto yielded little, but recently a new find has been made, and the material scattered in various museums has been brought together, so that von Huene[7] has been able to show that twenty species, representing seven genera, are to be found. Of these, however, only eight species are sufficiently represented to make it possible for them to be named. Of the seven genera six are represented in other species from California, Nevada, Spitzbergen, and Besano. The whole of the material seems to come from the Muschelkalk.

The Spitzbergen Trias vertebrates are, with a few exceptions, distributed in four horizons. If the lowest, the first horizon, is fixed at zero, they lie at something like the following distances from each other:

The new vertebrate horizon	360? m.
The upper saurian horizon	205–210
The lower saurian horizon	93
The fish horizon	0

With regard to stratigraphy in general, reference is made to the work by Nathorst.[16] Above the arenaceous beds, belonging presumably to the Buntsandstein,[23] which were previously referred to the Permian, come the Posidonomya slates. Near the base of these lies the fish horizon, and somewhat deeper than that part of the layer which from older Swedish ammonite finds was known to Mojsisovics.[15] Probably the lower saurian horizon also comes within this layer.

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The Posidonomya slates, as well as the following Daonella slates, with the upper saurian horizon, belong to the Muschelkalk. Above these bituminous slates again come arenaceous beds which, for the greater part at least, ought to represent the Keuper. Within these lies the new vertebrate horizon.

The age relations of the better known Triassic ichthyosaurians thus becomes the following: To the Middle Triassic belong the finds in Germany, Nevada, and Spitzbergen, and to the Upper Triassic those in California and at Besano.

MIXOSAURUS AND PHALARODON

The genus *Mixosaurus* was erected by G. Baur[12] in 1887, and was founded on the Lombardy species *M. cornalianus* Bass., which now, by the researches of Repossi[18] and myself,[21] is pretty well known. In 1891 E. Fraas[5] incorporated with this genus, under the name *Ichthyosaurus atavus,* the species originally described by Quenstedt.[17] This procedure was accounted for by *I. atavus* having elongated forearm bones, sparse and dimorphous teeth, etc., characters which one now knows are peculiar to Triassic ichthyosaurians in general, and therefore cannot be used as generic characters. For the same reason Dames[3] took this view. Judging by the little hitherto known of *I. atavus,* it cannot belong to the genus *Mixosaurus.*

For still less important reasons Dames referred to the genus *Mixosaurus* the smaller of the only two species from the Spitzbergen Triassic. This, however, has turned out more successful, and new material having been added since 1909, I did not hesitate, in 1910, to class *Mixosaurus nordenskiöldi* with this genus. In this view I have been further strengthened since I succeeded in obtaining material of the Besano species and studied Repossi's original specimens in Milan.

In 1910 a work by Merriam[12] was published in which a new species, *Phalarodon fraasi,* was described. It then appeared that I had probably made a mistake, in so far as I had also classed the Phalarodon-like jaw fragments with *Mixosaurus nordenskiöldi* (1910, pl. 5, figs. 10, 12, and 13). In so doing I conceived the possibility of a difference in sex of such a nature that the less pronounced dimorphous teeth might represent, for example, young females and the more developed dimorphous teeth old males. My figure 10 shows a transition, on the one hand, from those which I still wish to class with *Mixosaurus nordenskiöldi* (figs. 9 and 11) and the perfectly Phalarodon-like ones in figures 12 and 13.

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In his work of 1911 Merriam[13] called attention to the similarity between *Phalarodon* and certain of my specimens, and I now consider it probable that the jaw fragments (pl. 5, figs. 12 and 13) at least, are to be connected with *Phalarodon,* which is a special type. After having seen comprehensive material of *Mixosaurus cornalianus,* I have found that the appearance of the teeth is very constant in different specimens, and from investigations by Dollo[4] of the mosasaurian *Globidens fraasi,* in which also *Phalarodon* is treated, it has also become probable that the posterior teeth of *Phalarodon* indicate a very diverging diet. As, however, there is in the grade of dimorphism of the teeth a very even transition from *M. cornalianus* over *M. nordenskioldi* and to the pronounced *Phalarodon* type, one ought perhaps to await a more complete knowledge of the crania of the *Mixosaurus* species, and new discoveries of remains of *Phalarodon,* of which hitherto only cranium parts are known, before one decides where the boundary between *Mixosaurus* and *Phalarodon* should be fixed, and whether the difference really is so great that it warrants the setting up of a new genus. For the present I will, therefore, keep *M. cornalianus* and *M. nordenskioldi* together within the same genus. To it belongs, with a certain degree of possibility, also *Cymbospondylus? natans* Merriam from Nevada. The anterior limb indicates, as will be seen by the accompanying figures (figs. 1 and 2), great similarity, especially to the species from Spitzbergen. The piece of the vertebral column, which Merriam classes with this species, does not contradict this supposition. It is perhaps not excluded that *Phalarodon fraasi* is the cranium of this species, for it originates from the same horizon.

The pelvic arch of *M. nordenskiöldi* is, as I have previously shown, almost identical with that of *M. cornalianus,* which has also a foramen pubicum.

As Merriam has rightly observed from my figure of the vertebral column, a portion of the tail is missing, but it is seen from loose vertebrae that the tail has not narrowed off suddenly, as with the whales, but very slowly, as with other ichthyosaurians. The part of the tail that lay behind the caudal fin must therefore have been very long. Merriam also conceives of the possibility of my having placed the pelvis too far back. This I do not consider probable, for I am very sure about the position of the pelvis. The difficulties that Merriam finds in the, with all this connected, placing of the caudal fin disappears if one takes another view of the origin of the caudal fin than Merriam. I have imagined that the caudal fin is a dorsal fin,

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which moves backwards, and first during the Jura period reaches the tip of the tail, where it becomes stationary, after which the portion of the vertebral column located within the fin begins to shrink. In this view of mine I have also been strengthened by Fraas'[6] description of the remains of a very young specimen of *Ichthyosaurus quadriscissus* Quenst., which in this respect constitutes something between, for instance, *Mixosaurus nordenskiöldi* and the full-grown *I. quadri-*

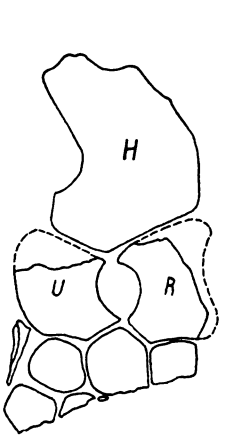

Fig. 1.—*Mixosaurus? natans* Merriam. Anterior limb, × ½ (combined after Merriam and partly restored).

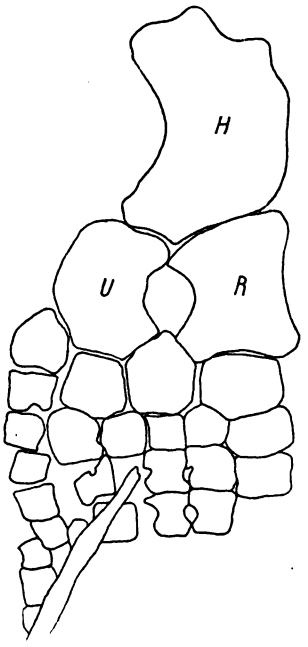

Fig. 2.—*Mixosaurus nordenskiöldi* Hulke. Anterior limb, × ½ (after Wiman).

H, humerus; *R*, radius; *U*, ulna.

scissus. It then also becomes perfectly natural that the fin-defining downward bend of the tail in the older Middle Triassic *M. nordenskiöldi*, lies more forward than in the younger Upper Triassic *M. cornalianus*, in which the fin ought to have had time to move a little farther back. In *Cymbospondylus petrinus*, also Middle Triassic, the tail-curve lies, according to Merriam, still farther back than in the younger *M. cornalianus*. This, however, need prove nothing more than that in another quite different tribe of ichthyosaurs the move-

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ment of the caudal fin took place at a quicker pace than in the mixosaurians.

PESSOSAURUS AND SHASTASAURUS

Of the material from the upper saurian horizon of Spitzbergen, which I have tried to unite with *Pessosaurus polaris* Hulke, only the coracoid, humerus, radius, ulna and a few podial bones are found to-

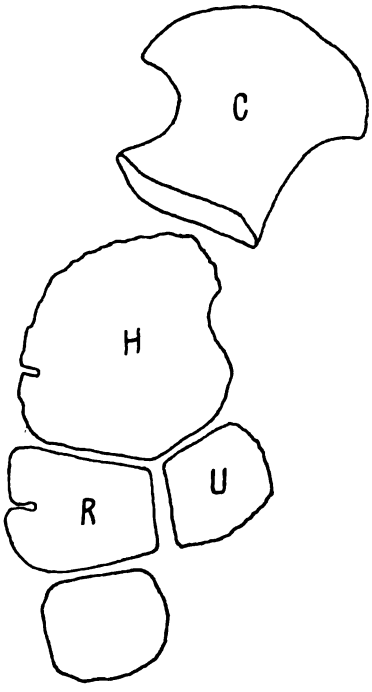

Fig. 3.—*Shastasaurus osmonti* Merriam. Anterior limb, × ⅙ (after Merriam).

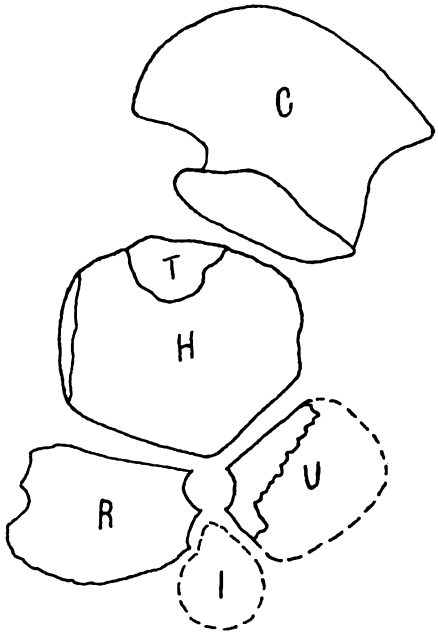

Fig. 4.—*Pessosaurus polaris* Hulke. Anterior limb, × ¼.

C, coracoid; *H*, humerus; *R*, radius; *U*, ulna; *I*, intermedium; *T*, trochanter.

gether. As the ulna was destroyed in the preparation, I have not figured it before, although a very important fragment in juxtaposition to the radius is left. The bone had, however, the shape, very nearly at least, that I have reproduced in the accompanying figures (figs. 3 and 4). This neglect on my part has doubtless contributed to the peculiarities of the species, over against *Shastasaurus,* not having appeared as clearly as could have been desired. A comparison between

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the figures of *Pessosaurus polaris* Hulke and *Shastasaurus osmonti* Merriam proves that quite another type is before us. The coracoid undeniably shows a certain likeness to the same bone in *Shastasaurus,* but it is more elongated longitudinally, which, however, is of little importance. This type of humerus differs widely from all the American species and recurs only in *Pessopteryx,* the species of which, one and all, possess this thick, round type. Also radius and ulna have an appearance diverging very much from all other forms, caused by their belonging to a species with short, broad fins, within which the displacement of the bones has proceeded farther than with any other Triassic ichthyosaurian. For though the, for all such typical remaining portion of the forearm, elongation still is marked by the round not cartilage-filled hole between the radius and the ulna, the intermedium has pressed in just as far between the forearm bones as, for instance, in the Jurassic *Ichthyosaurus communis* Conyb. The fore limb of *Pessosaurus* thus shows arrangement and form of the bones quite different from the corresponding characters in *Shastasaurus.*

PESSOPTERYX AND OMPHALOSAURUS

The material from the Lower Saurian horizon of Spitzbergen is very difficult to handle, as it consists of mere loose bones and bone fragments which lie scattered on the float soil. Most of the bones are present in a very great number of specimens, and I still consider it probable that the majority belong to an ichthyosaurian which I have called *Pessopteryx nisseri.* In addition, some smaller species chiefly of the same time must be present.

To *Pessopteryx nisseri* I also referred, by way of proposal, and with much hesitation, a large number of jaw fragments with queer, button-like teeth in several rows. When I referred these teeth to an ichthyosaurian I imagined a change of diet something like the one that has now really been verified in *Phalarodon* and *Globidens.* That the teeth were set in several rows I imagined to be due to the fact that, for the greater part at least, they consisted of reserve teeth, not yet used, which in that case ought to be arranged much the same as with the crocodiles, although, as far as I have yet been able to ascertain, they lie wholly embedded in the bone substance. Resorption of bone substance is of course nothing unusual in connection with displacement of teeth and horny cases, and also the embryological origin of similar teeth ought to be histologically possible.

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These jaw fragments now seem to me to be somewhat less enigmatical, since Merriam has pointed out that they do not belong to an Ichthyosaurian. In 1906 Merriam[9] described a reptile, widely different from the ichthyosaurians but with a still uncertain systematic position, *Omphalosaurus*. It is found in the Middle Triassic of Nevada, and is thus approximately in the same horizon as *Pessopteryx*. The reproductions of the teeth of *Omphalosaurus* that are found in this work did not suggest to me any thought of the enigmatical teeth of Spitzbergen. Merriam, however, in 1911,[13] has shown the great similarity between the *Omphalosaurus* teeth and the teeth referred by me to *Pessopteryx,* and since Merriam and Bryant[14] the same year produced new figures of *Omphalosaurus* teeth I can myself

Fig. 5.—Phalanges from the Lower Saurian horizon on Spitzbergen, × ½ (after Wiman).

state the identity. But seeing that the teeth are identical, in what relation do then *Omphalosaurus* and *Pessopteryx* stand to each other? Of the former only parts of the cranium with teeth and biconcave, ichthyosaur-like cervical vertebrae are known, and, again, of the latter vertebrae, extremity and girdle bones are found. Therefore a comparison cannot be made. One can, however, think of two possibilities. The one is, that all of the material represents *Omphalosaurus*. Merriam seems to be inclined to this interpretation. One would then have to imagine a reptile with a relatively short head and a body that in detail had developed on the same line as *Ichthyosaurus*. Such a parallelism is of course not inconceivable, but less probable. The other probability is that an ichthyosaurian *Pessopteryx* is before us, but that, together with its bones, jaw fragments of *Omphalosaurus* occur. It is easily possible that these very jaw bones have constituted the most lasting part of the skeleton. In favor of a foreign intermixture also speaks the fact that together with the *Pessopteryx* bones occur very

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numerous phalanx-like bones of different length, which, as I have previously pointed out, cannot be located in an ichthyosaurian skeleton, but which might possibly belong to the *Omphalosaurus* teeth. That an ichthyosaurian *Pessopteryx* should develop a peculiarly formed humerus, which is identically like that of another ichthyosaurian, *Pessosaurus,* from the same region, is by far not so strange as that a reptile of an altogether different tribe, *Omphalosaurus,* should acquire just this humerus type. I therefore consider the probability larger that in addition to *Pessopteryx nisseri* also a representative of the genus *Omphalosaurus* is before us.

FAUNAL RELATIONSHIPS

I can therefore agree with Merriam that the marine Triassic saurians of Spitzbergen and of central and southern Europe show a noticeable similarity with those of the Triassic of North America. The *Mixosaurus* species *nordenskiöldi, cornalianus,* and *natans* are undoubtedly nearly related. If, then, a separate genus, *Phalaradon,* be added, common to Spitzbergen and western North America, this of course increases the similarity. Judging by von Huene's previous communications, a number of American ichthyosaurian genera are also to be found in the middle European Muschelkalk. *Omphalosaurus,* wherever it belongs, is also a genus common to Spitzbergen and North America.

If, however, important similarities exist between the Triassic marine saurians in the Old and the New World, there are also greater dissimilarities. These differences appear among the ichthyosaurians. In western North America are found numerous species of the genera *Cymbospondylus, Toretocnemus, Merriamia, Delphinosaurus,* and *Shastasaurus,* which do not appear in Europe or Spitzbergen. The Central European Muschelkalk no doubt also contains one or two specific types, and *Pessosaurus* and *Pessopteryx* are characteristic of Spitzbergen.

If we turn to other reptile groups that are not adapted to a pelagic mode of living in such a high degree as the ichthyosaurians the dissimilarities of course become greater. In the Alpine Trias two nothosaurians, *Pachypleura* (*Neusticosaurus*) from Besano and the somewhat younger *Lariosaurus* of Perledo, are found. In the Middle European Muschelkalk are found numerous nothosaurians and placodonts. The marine Trias beds in Spitzbergen also contain several evidently

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marine labyrinthodonts,[22] and in western North America are found thalattosaurians[6, 11] to which one nowhere has found any analogy.

Lastly, I would like to draw attention to a hitherto utterly neglected region containing marine Triassic saurians, namely, Arctic North America, where we have long known that ichthyosaurians are to be found. Triassic beds lie exposed on Prince Patrick Island, Parry Islands, and on the western side of Ellesmere Land. One or more of these islands could, no doubt, be reached by ship, at least during favorable years, and from the eastern parts collections could be freighted down on sledges across Ellesmere Land, to the eastern shore of which one can come with ships by Smith Sound. How accessible the occurrences on either side of the northern part of Smith Sound are I do not know.

Transmitted February 25, 1916.

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Vol. 10, No. 6, pp. 75-85 Issued November 18, 1916

NEW MAMMALIAN FAUNAS FROM MIOCENE SEDIMENTS NEAR TEHACHAPI PASS IN THE SOUTHERN SIERRA NEVADA

BY

JOHN P. BUWALDA

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Introduction

During the past five years expeditions under the direction of the Department of Palaeontology of the University of California have made considerable collections of Tertiary mammalian fossils in formations near Barstow and at Ricardo, in the Mojave Desert. Mammalian material has also been obtained in sections containing marine formations in the Southern San Joaquin Valley, on the western or opposite side of the southern Sierra Nevada. Study of this material from the Mojave Desert and the San Joaquin Valley has yielded important information regarding the history of mammalian life in these regions. With the geologic data obtained it is being made the basis for a beginning in the correlation of events in the Tertiary palaeontologic and geologic history of the Great Basin and Pacific Coast provinces.

With a view to contributing to the solution of this general problem of Cenozoic correlation between the Great Basin and Pacific Coast

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provinces, the writer examined an area of sedimentary deposits near Tehachapi Pass, in the southern Sierra Nevada. This area lies directly between the San Joaquin Valley and the Mojave Desert. Because of its position it seemed probable that its study would yield critical information bearing upon the question of correlation between the two provinces. Reconnaissance examinations by the writer in the winter of 1912 and in the summer of 1914 had, moreover, suggested the probability of the presence of mammalian fossils in the exposures of sedimentary strata in the Tehachapi area.

As the result of several weeks' work in the Tehachapi Pass region in November and December, 1914, two fossil faunas were secured at quite widely separated horizons. More material was obtained in June, 1915, in the collection of which the writer was ably assisted by Clarence L. Moody, James M. Douglas, and Edward Thacher.

Though the collections are not large, they are thought to contribute new information relating to the history of the Mammalia of western North America, and bearing on the geologic history of the southern Sierra Nevada and adjacent regions.

This paper is a summary statement of the composition and relationships of these faunas. Detailed descriptions of the faunas and a discussion of the geologic results are to follow.

OCCURRENCE

The Tertiary formations in which the mammalian faunas are found in the Tehachapi region are in part an extension of beds first brought to notice by Professor Andrew C. Lawson,[1] who described strata exposed in the vicinity of Monolith and lower Cache Creek, near Tehachapi Pass.

The formations are included in a section of volcanic and terrestrial materials extending over an area of seventy-five to eighty square miles or more of the summit region of the southern Sierra northeast of the town of Tehachapi. The total thickness of the formations is probably not less than four or five thousand feet. Constituting the group are basic lava flows, volcanic agglomerates, massive pumiceous tuffs, stratified ash beds, terrestrial sandstones, clays, cherts, and fanglomerates. The fossiliferous horizons are probably stratigraphically near the middle of the section. The whole succession of strata records recurrent volcanic activity, with intervening periods of subaerial and lacustral deposition. The angular fanglomeratic character of the coarser

[1] Univ. Calif. Publ., Bull. Dept. Geol., vol. 4, pp. 431–462, 1906.

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sediments and the similarity of the finer beds to playa lake deposits strongly suggest that the climate was arid or semi-arid, rather than humid. The presence of palm leaves near the lower of the horizons at which mammalian remains were found does not conflict with this inference.

Since their deposition the series of deposits containing the faunas have been folded, with dips up to 30 degrees. The tilted strata have been in part cut away by erosion, and their deep dissection has afforded excellent opportunity for securing collections of the contained fossil remains. The fossils were obtained from badland surfaces, on which they lie where the matrix has been blown or washed away, and from rocky shelves on the bluffs in which the fossils were embedded.

The two localities from which the faunas were collected are situated about three miles apart. The lower fauna was found in sandstones, containing chert layers, about nine miles northeast of the town of Tehachapi, and one mile northeast of Phillips Ranch, which is on Sand Creek, a tributary of Cache Creek. This assemblage may be known as the Phillips Ranch fauna. The second or younger fauna occurs in coarse sandstones and fine fanglomerates exposed along the south fork of upper Cache Creek, about three and one-half miles east of Phillips Ranch. This upper mammal-bearing horizon passes under Cache Peak on the divide between Cache Creek and Jawbone Cañon. This will be known as the Cache Peak fauna. Strata of an estimated thickness of five hundred feet separate the horizons of the Phillips Ranch and Cache Peak faunas. It is quite possible that an unconformity occurs in the section between the two faunas; evidence suggesting an erosion interval was noted in upper Oil Canyon, a tributary of Cache Creek from the south.

The Phillips Ranch fauna was obtained at a single locality extending only a few hundred feet along the outcrop of the beds and through but fifty or seventy-five feet of the strata. The Cache Peak material was collected from exposures distributed over an area perhaps two miles long and extending through several hundred feet of beds.

PHILLIPS RANCH FAUNA

The collection from the lower horizon near Phillips Ranch includes the following forms:

Merychippus, n. sp.
Camelid, large
Camelid, small
Moropus, sp.
Merycodus? sp.
Carnivore, indet.
Canid, indet.
Felid, indet.

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The horses of the Phillips Ranch fauna are of a type in or near the genus *Merychippus,* but possibly represent a new subgenus of that group less advanced in tooth structure than typical *Merychippus.* They are represented by upper and lower cheek-teeth and by a number of limb bones. The upper cheek-teeth are short hypsodont, the height being about equal to or a little greater than the transverse diameter in well worn teeth. The teeth are small, those in the middle of the series ranging from 15.6 to 17.1 mm. in anteroposterior diameter and from about 15 to 16.4 mm. transverse diameter. Height of worn teeth on the outer side is 15 to 18 mm., on inner side 10.2 to 12.2 m. They are relatively narrow transversely compared with the teeth of typical species of *Merychippus.* The outer and inner faces are not approximately parallel as in strictly prismatic teeth, but approach each other somewhat toward the summits of the teeth. The crowns are slightly curved. They are well cemented, but the cement covering is not heavy. The outer faces of paracone and metacone are flat or have a very faint median rib. The mesostyle is prominent, narrow, and may be of nearly equal width from base to summit of tooth, or may flare slightly at the base. The protoconule and metaconule are slightly larger than protocone and hypocone. The protoconule is slightly crescentic and is broadly connected with the oval protocone. The metaloph is completely connected with ectoloph, but is usually not connected with protoloph because of imperfect development of the posterior horn of the protoconule. The fossettes are well cemented, with one or two crinkles in the enamel borders. The prefossette is usually open on the median or inner border between protoloph and metaloph. The postfossette is sometimes closed and sometimes open between hypocone and hypostyle.

The upper cheek-teeth are more advanced than those of *Parahippus* and the other genera of the Anchitheriinae in the greater height of the crowns and in their prismatic form, in their strong cementation, in the relatively large size of protoconule and metaconule compared with protocone and hypocone, and in the tendency to close the fossettes. They are relatively primitive compared with described forms of *Merychippus* in their small size, shorter crowns, subequality in size of protocone and protoconule, in the imperfect development of the posterior horn of the protoconule, and in the general openness of the fossettes on the inner side.

The characters are in a measure those assigned by Gidley[2] to hypothetical genera of a group "C" of division "Anchitheriinae

[2] Gidley, J. W., Bull. Am. Mus. Nat. Hist., vol. 23, p. 868, 1907.

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Leidy": "Inner conules (pr and hy) smaller than median conules (pl and ml), protoconule semi-crescentic; partially or completely united with the metaloph; . . ."

The lower cheek-teeth of this equid form are all of one type, characterized by being distinctly hypsodont, and well cemented. Their length is approximately one to one and one-half times their anteroposterior diameter. The metaconid-metastylid column is well developed. The marked groove between the metaconid and metastylid persists nearly to the base of the tooth. The lower cheek-teeth seem in some respects more advanced than the upper, but certainly represent the same form, as the upper and lower teeth of the same individual have been found together.

In one specimen (no. 21692) lower milk teeth are present in the jaw with the permanent teeth. The deciduous teeth are of the short-crowned type and bear a thin cement layer.

With the horse teeth are three astragali and scattered limb bones representing small forms. One of the three astragali is much smaller than the others and possibly represents a type distinct from that indicated by the other material.

The camels of the Phillips Ranch fauna are known from cheek-teeth, an astragalus, a distal portion of a radius, a distal portion of a tibia, and by a number of foot bones. The material probably does not permit of specific determination, but difference in the size of the teeth suggests that a large and a small species of camel are present.

Moropus is indicated in the assemblage of species by a portion of a lower jaw containing three premolars and a molar, all little worn. Compared with *Moropus elatus* Marsh, the teeth in this jaw are considerably smaller and are relatively narrower transversely.

An incomplete calcaneum closely resembles that of the antelope-like *Merycodus*.

A toothless carnivore jaw represents a small form which is probably not generically determinable.

A part of a lower jaw, probably of a canid, and a portion of a tooth, apparently a felid, likewise do not admit of exact identification.

The evidence as to age of the Phillips Ranch fauna is furnished principally by the horse material. The *Merychippus* is possibly so primitive that it should be set off as a new subgenus. *Merychippus* is usually held to range from middle Miocene to early Pliocene. It appears that this faunal stage is not younger than middle Miocene and may represent a somewhat earlier stage of that period.

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CACHE PEAK FAUNA

The Cache Peak fauna includes the following forms:

Merychippus, n. sp., *a*	Merycochoerus(?), sp.
Merychippus, n. sp., *b*	Dromomeryx, sp.
Hypohippus, sp.	Merycodus, sp.
Camelid, sp., *a*	Felid, sp.
Camelid, sp., *b*	

Of the three forms of horses only one is represented by sufficient material to make possible a full study. Of this type there were obtained a nearly complete skull (no. 22254, Univ. Calif. Loc. 2735) with complete upper cheek dentition, a complete femur, complete metapodial region with lateral elements and phalangeal series, and the extremities of a number of other limb bones. No lower teeth of this individual were found.

The notable characters of the dentition of this specimen are as follows: Upper cheek-teeth short hypsodont and well cemented. Mesostyle strongly developed. Protocone flat oval in cross-section and slightly smaller than the protoconule, distinctly connected with the protoconule in every tooth in the skull. Protoconule and metaconule not notably crescentic. Postfossette closed in all the teeth; prefossette closed on the inner or median side in seven of the twelve teeth.

Several other upper cheek-teeth from the Cache Peak horizon, some unworn, are of the same type as those of no. 22254, and exhibit no new characters. In the course of wear the protocone of these teeth would be disconnected from the protoconule until approximately the upper half of the tooth had been worn away.

Several lower cheek-teeth in the collections, presumably representing the form seen in no. 22254, are also quite heavily cemented.

The type of horse represented by these upper and lower cheek-teeth is certainly to be characterized as a species of *Merychippus* as this group is at present defined, and is not one of the most primitive members of the group.

The second form of horse in the Cache Peak fauna is known only by parts of three upper cheek-teeth, two of which fortunately exhibit the protocone-protoconule relation. These teeth are badly worn, but the crowns appear to have been rather short hypsodont, well cemented, and somewhat curved. The most notable feature is the fact that the protocone as shown in no. 21693 is widely disconnected from the protoconule to the very base of the tooth, and that it is short oval in cross-section. The protoconule in this specimen is distinctly larger than

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the protocone, is markedly crescentic in outline, and is connected with the metaloph. The last three characters are among those which set off the *Merychippus* group from the earlier horses. So far as can be judged from the scanty material, this form should be included within the genus *Merychippus,* but the disconnected protocone indicates that it probably lies within that division of the genus leading toward the *Hipparion* stock rather than within the division which probably gave rise to *Protohippus, Pliohippus,* and other forms with connected protocone.

The *Hypohippus* material consists of three upper cheek-teeth. The advanced state of wear will probably not permit the safe reference of the form represented by the teeth to any of the described species of *Hypohippus.*

The collection from the Cache Peak horizon includes a considerable amount of camel material, consisting of imperfect limb bones, with a few parts of teeth. The remains indicate the presence of at least two forms. Fragmentary teeth and some of the limb bones represent a species near *Procamelus.* Certain of the other parts, such as a crushed proximal extremity of a metapodial and two imperfect astragali, represent a camel decidedly larger than the first species mentioned.

Of the two teeth indicating the presence of an oreodont in the fauna one is presumably *Merycochoerus;* the other may be generically distinct.

The antelope-like *Dromomeryx* is represented in the Cache Peak fauna by two lower teeth. While it is not desirable to attempt a specific determination with such scanty material, the characters of the genus are well shown in the accessory median tubercle, the accessory anterior ridge developed from the cingulum, and in the roughened surface of the enamel. The "Palaeomeryx fold" on the anterior external crescent is shown on one of the teeth. *Dromomeryx* has been reported from middle Miocene to early Pliocene.

The fragmentary *Merycodus* material indicates a small species of that genus. This form may be the same as that occurring in the Barstow fauna.

A felid is known in the fauna by the distal portion of a metacarpal or metatarsal.

RELATIONSHIPS OF THE FAUNAS

A comparison of the Phillips Ranch and Cache Peak faunas must at present be based largely upon the horses represented in the two

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collections. *Moropus* occurs only in the former fauna, while *Merycochoerus*(?) and *Dromomeryx* are found only in the latter, but the collections are not sufficiently large to make the absence of a form from one fauna and its presence in the other significant. *Merycodus* is present in the collections from both localities, but the material is too scanty to allow an accurate comparison.

Of the horses, the species from the Phillips Ranch horizon has much smaller and much more primitive cheek-teeth than either of the forms in the Cache Peak fauna. The horse astragali from the Phillips Ranch horizon are all of a smaller type, while there are in the collections from the upper horizon astragali of a larger type as well.

The evidence of the camel material is not emphatic, but the larger size of most of the camel teeth and foot parts in the Cache Peak fauna tends to confirm the view that this assemblage represents a more advanced stage.

The Phillips Ranch fauna is quite certainly considerably older and less advanced than the assemblage from the Cache Peak horizon.

In considering the relations of the Phillips Ranch and Cache Peak faunas to other groups it seems desirable to compare them with faunas known from neighboring areas. In the Mojave Desert the Ricardo fauna, known from considerable collections to be of approximately lower Pliocene age, occurs about twenty miles to the northeast; the Barstow fauna, also well represented by material and of approximately upper Miocene age, is found about eighty miles to the east. In the southern San Joaquin Valley on the opposite side of the southern Sierra a meager collection obtained in the Tejon Hills is of approximately very late Miocene or lower Pliocene age.

The species of *Merychippus* found in the Phillips Ranch fauna is very different from any species found in the Barstow upper Miocene collection, being much more primitive. The camels do not permit of an exact comparison because of scantiness of the Phillips Ranch material, but they appear to be different. The species of *Merycodus* may be the same as that from Barstow, but with the material at hand a certain determination cannot be made.

The horse material from Phillips Ranch resembles still less any of the horses found in the Ricardo fauna, being much more primitive. It is likewise less advanced than the horse species obtained in the Tejon Hills in the southern San Joaquin Valley.

The Phillips Ranch fauna certainly represents a stage of evolutionary development much earlier than the Barstow, Ricardo and Tejon Hills faunas.

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The horses of the Phillips Ranch fauna appear more primitive than those of either the Mascall or the Virgin Valley. They may be of a middle Miocene stage, but older than the stage of either the Mascall or the Virgin Valley. The lower, or Phillips Ranch horizon, appears to represent the oldest stage in the development of mammalian life above the Oligocene known thus far in the region west of the Wasatch.

The Cache Peak fauna has been stated to be more advanced than that from near Phillips Ranch. The *Hypohippus* of the Cache Peak assemblage is probably specifically distinct from that found at Barstow. The complete skull with dentition representing *Merychippus* differs somewhat in the details of the facial region and in its dentition from *Merychippus calamarius,* a common form at Barstow, but appears to be quite near that species. The Hipparion-like horse teeth of the Cache Peak fauna have the protocone more distinctly separated than it is in the nearest allied type in the Barstow fauna; this wide separation is probably an advanced character. On the other hand, the Barstow fauna contains horses which have longer and heavier lower molars than any found in the Cache Peak assemblage.

The *Dromomeryx* teeth from the Cache Peak horizon seem considerably shorter and less advanced than the form found at Barstow. The *Merycodus* cannot be compared satisfactorily. The *Merycochoerus* form may be different, but the material is too fragmentary to permit a certain comparison.

Comparing the Cache Peak with the Ricardo, no form is known to be common to the two faunas, although the *Merycodus* may be the same. The horses in the lower part of the Ricardo section are mainly very advanced types of *Pliohippus* and *Hipparion.*

The horses obtained in the Cache Peak horizon are all different from those so far known from the Tejon Hills, and probably represent a stage somewhat older.

The Cache Peak fauna is probably considerably older than the Ricardo, probably somewhat older than the Tejon Hills, but probably does not differ greatly in age from the Barstow.

The Cache Peak fauna represents a stage in advance of that found at Phillips Ranch. The Cache Peak fauna may be late middle Miocene or upper Miocene; it may furnish a transition stage between the Phillips Ranch and the Barstow faunas, but it is much nearer to the Barstow than to the Phillips Ranch.

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GEOLOGIC SIGNIFICANCE OF THE FAUNAS

The faunas, consisting as they do in large part of horses, camels, and antelope-like forms, point to a plains or open valley environment in this region in middle Miocene time.

The deposits in which the faunas occur are of types which suggest that they were laid down under subaerial conditions as waste slope and playa lake deposits; the evidence for this view is corroborated by the occurrence of the mammalian remains, which are usually scattered and frequently much gnawed by rodents. The angularity of the coarser terrestrial deposits precludes their fluviatile origin, and the lack of classification and bedding in the fine materials militates against their being in any large measure of truly lacustrine origin. The faunas and the formations in which they occur thus indicate that the climate was one of semi-aridity or aridity. Fossil wood and palm leaves at one or more horizons probably do not negative this view.

The age of the faunas being established as approximately middle and upper Miocene respectively, stratigraphic relations indicate that important crustal movements occurred in this region between Jurassic and middle Miocene time and in post-middle-Miocene time.

The movements subsequent to the Jurassic and antecedent to the middle Miocene are indicated by the relation of the mammal-bearing group to a succession of sediments which lie with marked unconformity below these strata and rest unconformably on the plutonic rocks of presumable Jurassic age. This lower sedimentary series, which is well exposed along lower Oil Cañon, has been deformed to the extent that the strata attain a vertical position over much of the area in which they are exposed. It is not improbable that deformative movements affected the territory immediately previously to the deposition of the mammal-bearing group, inasmuch as the topography on which these beds were laid down was one of some relief and indicates active erosion immediately preceding their deposition.

The crustal movements subsequent to middle Miocene time in the Tehachapi Pass region are evidenced by the folding which the mammal-bearing group has suffered since its deposition; dips of twenty to thirty degrees are common in the strata. Following this folding, erosion cut away no small part of the total mass of the accumulated sediments and probably produced on the region a land surface of gentle relief. The latest diastrophic event was the faulting along the southeastern base of the present range, by which the mountain area was displaced

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vertically 2500 to 3000 feet with respect to the adjacent Mojave Desert area. This zone of displacement fractured the strata containing the middle Miocene mammalian remains, so that if there were no other basis for determining the date of the great displacement which gave the southern Sierra Nevada its present orographic features, the lower limit in time would be defined by the upper Miocene age of the younger of the two faunas. This would indicate that the faulting occurred in late Miocene or post-Miocene time. This fact is of interest when it is recalled that some geologists have set earlier dates for the faulting by which the northern Sierra Nevada attained its present elevation above the Great Basin.

Transmitted April 9, 1915.

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AN AMERICAN PLIOCENE BEAR

BY

JOHN C. MERRIAM,
CHESTER STOCK, AND CLARENCE L. MOODY

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AN AMERICAN PLIOCENE BEAR

BY
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CHESTER STOCK, AND CLARENCE L. MOODY

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INTRODUCTION

Although the bear group is well known in some of the latest Cenozoic faunas of the Western Hemisphere, the one or two occurrences of very fragmentary material reported to represent this family in American deposits older than Pleistocene have been considered doubtful. In the Old World, members of the Ursidae are found in formations ranging from Miocene to Recent, and in view of available evidence it is assumed generally that the New World bears are comparatively recent immigrants, the earliest arrivals having come from Asia to North America near the beginning of Pleistocene time.

The North American Pleistocene bears comprise two groups; the *Ursus* type, represented by forms closely related to existing species of this continent; and the peculiar short-faced arctotheres, having no living representatives in North America, but closely related to the spectacle bear of South America. In the Pleistocene of South America *Arctotherium* is known by several species, but *Ursus* is not represented. There is then apparent basis for the theory that *Arctotherium* arrived in North America in advance of bears of the *Ursus* type and reached

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South America before *Ursus* crossed from the Old World. If this view expresses the history of migration of bears in America, remains of *Arctotherium,* or of a type ancestral to this genus, might be expected in earliest Pleistocene or Pliocene deposits of North America. The absence of *Arctotherium* and of well authenticated remains of near relatives of this division of the bear group from North American deposits older than those containing *Ursus* has sometimes been interpreted to indicate the migration of *Arctotherium,* or of its ancestors, to South America by some route other than that through North America.

In the course of a special study of the later Tertiary deposits of eastern Oregon carried on by the Department of Palaeontology of the University of California in the summer of 1916, remains of a member of the bear group were discovered by Chester Stock and Clarence L. Moody in beds of the Rattlesnake Pliocene of the John Day region. The significance of this discovery, especially with relation to other studies on correlation and migration of Tertiary mammal faunas, makes desirable a statement of the evidence in advance of a full report on the Rattlesnake fauna.

OCCURRENCE

Remains of the Pliocene bear (no. 22362) were found in the Rattlesnake formation exposed on the East Fork of the John Day River in northeastern Oregon. The locality is situated near the center of N.W. ¼ sec. 30, T. 12 S., R. 26 E., Willamette Base Line and Meridian, Grant County, Oregon, approximately five and one-half miles west of Dayville, and not over three-fourths of a mile south of the type section of the Rattlesnake formation. The specimen was found on a low ridge between Rattlesnake Creek and Little Rattlesnake Creek.

In the typical area the Rattlesnake formation is tilted at an angle of approximately five degrees and rests upon a basement formed by sharply deformed, truncated strata of the Mascall Middle Miocene. The present canyon of the John Day River cuts through the basin of accumulation of the Rattlesnake. In the bottom of this canyon Pleistocene mammal remains are found in terrace deposits laid down after the canyon had attained approximately its present form. The stage of the Rattlesnake is thus limited on one side by antecedent Middle Miocene and by the period of deformation and extensive erosion intervening between deposition of the Mascall and beginning accumu-

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lation of the Rattlesnake. On the other side this stage is limited by the date of subsequent Pleistocene terraces and the period of canyon cutting intervening between the close of the Rattlesnake and beginning accumulation of the terrace deposits.

The known mammalian fauna of the Rattlesnake comprises between twenty and thirty species. The available representation will be fully discussed in an early publication. The horses are presumably the most important elements of the fauna for purposes of palaeontologic and geologic correlation. The Equidae are represented by species of the *Hipparion* and *Pliohippus* groups having their nearest relatives in beds referred to the early Pliocene of the Great Basin and Pacific Coast provinces. The view that the Rattlesnake fauna is related to that of the Thousand Creek Pliocene in Nevada receives support through the discovery of a horn-core of the peculiar antelope *Sphenophalos* in the Rattlesnake, in the course of the past season's work. This antelope has heretofore been known only from the Thousand Creek, where it occurs in association with twisted-horn antelopes of the *Ilingoceros* type.

In the locality at which the bear remains were found the Rattlesnake formation consists principally of a series of cross-bedded gravels alternating with varicolored tuffs and sands. A persistent rhyolite flow occurs at a high horizon in the formation. Pebbles in any single stratum are usually of comparable dimensions, but sharp changes occur in passing from one bed to another. Thus a stratum with bowlders attaining a diameter of one foot may immediately overlie a bed in which the largest pebbles have a diameter of not more than one-half inch. It was in a layer of the finer gravel that the bear remains were discovered. The bed seems to be lenticular, but this appearance may be due to occurrence of the gravels on the summit of a ridge. Mascall Miocene is exposed in the bed of Rattlesnake Creek to the north of the ridge upon which the gravels were found. This ridge has an approximate elevation of 150 feet above the level of the stream, thus placing the horizon at which the bear remains occurred well up in the Rattlesnake section. The erosion of Rattlesnake and Little Rattlesnake creeks has removed a large part of the formation south of the course of the former stream, and the section is known to be thicker toward the south. It has therefore not been found possible to ascertain the exact distance below the summit of the section represented by the bed in which the bear specimen was found. This horizon is believed to be stratigraphically within the limits of about 100 feet

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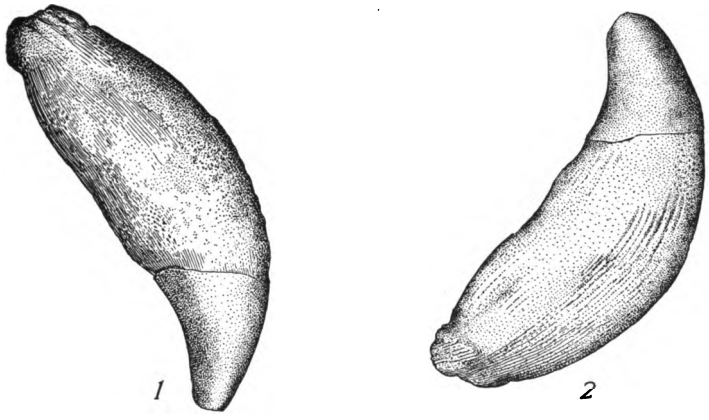
below the top of the rhyolite cap which forms the summit of the section at the type locality of the Rattlesnake.

The material representing the Pliocene bear includes the most important parts of the dentition, with six or seven representative elements of the limbs. There is good reason for considering that all of these specimens are derived from one individual. The preservation of the bones and teeth corresponds in general to that of other mammal remains obtained in the type section of the Rattlesnake formation.

DENTITION

The dentition of specimen no. 22362 from the Rattlesnake Pliocene includes practically all essential elements. From the upper jaws there are represented $I\frac{2}{}$, $I\frac{3}{}$, C, $P\frac{1}{}$, $P\frac{4}{}$, and $M\frac{2}{}$. The first upper molar is the only superior tooth of importance lacking. From the mandible only the canines and $M_{\frac{2}{}}$ were found. While it is to be regretted that the lower carnassial is not available, it should be noted that the forms most nearly related to this particular type show less variation in $M_{\frac{1}{}}$ than in $P\frac{4}{}$, $M\frac{2}{}$, and $M_{\frac{2}{}}$, all of which are at hand. The teeth present illustrate so fully the characters of the dentition as a whole that it is possible to make those comparative studies most important in determination of the relationships of this animal.

The two upper *incisors* present are much worn. So far as can be determined, they are of approximately the type seen in *Arctotherium,* but are larger than the corresponding elements in *A. simum* of the California Pleistocene.



Figs. 1 and 2. *Indarctos(?) oregonensis,* n. sp. Canine teeth, no. 22362, lateral view, × ½. Fig. 1, upper canine; fig. 2, lower canine. Rattlesnake formation, John Day Valley, Oregon.

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The large, heavy-fanged *canines* (figs. 1 and 2) are of the characteristic ursid type. The crowns of the upper canines have dimensions and proportions near those of *A. simum* of Potter Creek Cave. The roots may be larger relative to the size of the crown in the Rattlesnake specimen, but are not thicker in either transverse or anteroposterior diameter. In the lower canines, as in *A. simum*, the crowns are sharply concave on the posterior side. As in the upper canines, the crowns are near the size of those in *A. simum*, but the roots seem relatively large.

$P^{\frac{1}{1}}$ shows a form closely approaching that in the corresponding tooth of *A. simum*. This tooth (fig. 3) has a simple single root; and the crown consists of a single cusp, which extends to the anterior and posterior borders of the tooth in a well-marked longitudinal ridge or crest. The anterior ridge is noticeably convex on the outer side, and drops off abruptly or may be concave on the median side. A distinctly marked ridge of the cingulum on the antero-internal side unites anteriorly with the principal crest.

Fig. 3. *Indarctos(?) oregonensis*, n.sp. $P^{\frac{1}{1}}$, no. 22362, inner and occlusal views, natural size. Rattlesnake formation, John Day Valley, Oregon.

Fortunately both the right and left *upper carnassials* ($P^{\frac{4}{4}}$) are represented. These teeth (figs. 4*a* to 4*c*) are large and unusually well developed for members of the Ursidae. They differ markedly from all specimens of *Ursus* and *Arctotherium* known to the writers, and approach closely the type of $P^{\frac{4}{4}}$ known in the several species of *Hyaenarctos* (figs. 5 to 7). In the Oregon species the protocone is slightly larger than the tritocone. The deuterocone is very large, approximating in its cross-section the size of the protocone; and is situated so far forward that its anterior border is not posterior to the corresponding border of the protocone as in *Ursus* and *Arctotherium*. A large protostyle is present. The tooth is distinctly three-rooted, a large and widely divergent root supporting the deuterocone. The outer contour of the tooth shows a distinct concavity of the cingulum opposite the posterior side of the protocone.

$P^{\frac{4}{4}}$ differs from the corresponding tooth of *Arctotherium* in the relatively large size of the deuterocone; in the support of the deuterocone upon a distinct, widely diverging inner or third root; in the situation of the deuterocone as far forward as the protocone; and in the presence of a large, distinctly separated protostyle. In all of the characters in which this tooth differs from *Arctotherium* it re-

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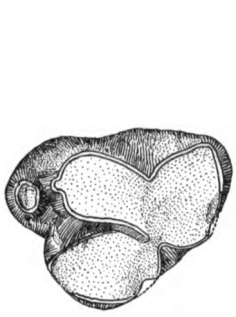
sembles *Hyaenarctos*. If isolated from other material, P^4 would certainly be considered as representing *Hyaenarctos* rather than the *Arctotherium* type.



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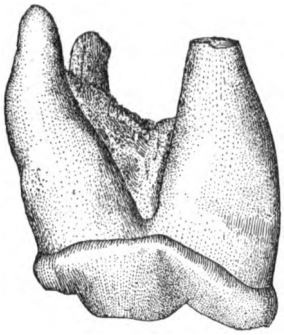

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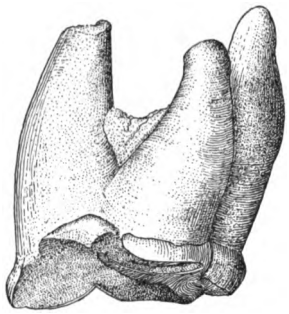

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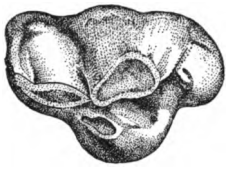

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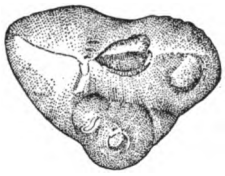

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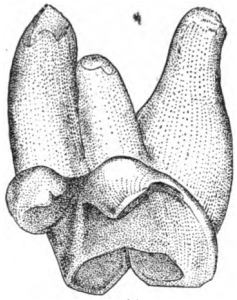

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Figs. 4*a* to 4*c*. *Indarctos(?) oregonensis*, n. sp. P^4, no. 22362, natural size. Fig. 4*a*, occlusal view; fig. 4*b*, outer view; fig. 4*c*, inner view. Rattlesnake formation, John Day Valley, Oregon.

Fig. 5. *Hyaenarctos insignis* P. Gervais. P^4, occlusal view, natural size. Montpellier, France. (After Gervais.)

Fig. 6. *Hyaenarctos palaeindicus* Lydekker. P^4, occlusal view, natural size. Siwalik beds, India. (After Lydekker.)

Fig. 7. *Hyaenarctos insignis* P. Gervais. P^4, inner view, natural size. Montpellier, France. (After Gervais.)

The upper carnassial of no. 22362 may be more primitive than that of *Arctotherium* in the anterior position of the deuterocone, and is more specialized in the presence of a large protostyle. In the Oregon form the anterior border of the deuterocone is situated approximately as far forward as the anterior border of the protocone, and

[1] Blainville, H. M. D., Osteographie des mammifères, Atlas 2, pl. 12, 1864.

[2] Pilgrim, Guy E., Records, Geological Survey of India, vol. 44, part 3, pp. 225–233, pl. 20, 1914.

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in *Hyaenarctos* the deuterocone tends to take the same position. In *Arctotherium,* and in bears of the *Ursus* type, the deuterocone is shifted far back and away from what is considered a normal position of this tubercle in the modern Carnivora, and is commonly situated opposite the notch between protocone and tritocone. The protostyle, which is so largely developed in the Oregon specimen and in *Hyaenarctos,* may be suggested in some arctothere specimens, and is figured by Blainville[1] in his illustration of the dentition of *Tremarctos ornatus,* the Recent South American relative of the arctotheres. It is therefore possible that a protostyle was at one time present on $P^{\frac{4}{}}$ of *Arctotherium.*

The *posterior upper molars* ($M^{\frac{2}{}}$) (figs. 8*a* to 9) of the bear from the Rattlesnake beds most nearly resemble those of the ursid type described by Pilgrim[2] from the middle or upper Siwalik beds of India under the name of *Indarctos salmontanus* (fig. 12). $M^{\frac{2}{}}$ of specimen 22362 resembles the type of *I. salmontanus* in its unusual relation of width to anteroposterior diameter, and in the stage of development of the heel. The anteroposterior and transverse diameters are almost identical with those of the type of *I. salmontanus.* The heel is a trifle longer in the Oregon specimen, but tends to be slightly wider in the Indian form. The difference in width of heel is possibly due in some part to difference in stage of wear in the specimens compared. As in *I. salmontanus,* the paracone and metacone of no. 22362 are clearly defined, the paracone being considerably larger than the metacone. In *I. salmontanus* the antero-internal region of the tooth consists of a large ridge divided into two tubercles of which the anterior is the larger. In the Oregon specimen the heavy antero-internal ridge is present, but the teeth are too much worn to show distinctly whether this area was divided into two elements. On the left tooth such a separation is suggested. In no. 22362, as in *I. salmontanus,* there is evidence of a large tubercle immediately behind the antero-internal ridge, corresponding evidently to the hypocone. This tubercle appears somewhat larger in Pilgrim's figure of *I. salmontanus* than it is in the left tooth of no. 22362. On the right tooth the hypocone may have been somewhat larger. The extreme posterior end of the heel consists of a transverse ridge which is largely worn down.

The proportions of the various areas of the tooth in no. 22362 are near those of the type of *Indarctos.* The anteroposterior diameter of the paracone is slightly less than it measures on Pilgrim's figure of

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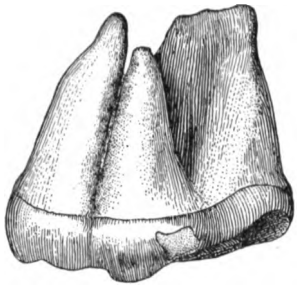
I. salmontanus. The distance from the posterior end of the paracone to the posterior end of the tooth is slightly greater in no. 22362, as is also the distance from the middle of the metacone to the posterior end of the tooth. The distance from the middle of the metacone to the anterior end of the tooth is greater in *I. salmontanus.*



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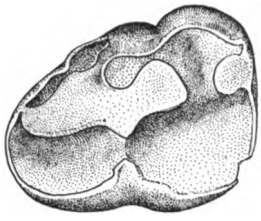

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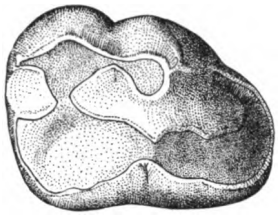

8b

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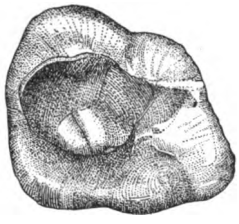

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Figs. 8*a* to 9. *Indarctos(?) oregonensis,* n. sp. M^2 of right and left sides, no. 22362, natural size. Fig. 8*a*, M^2 of left side, outer view; fig. 8*b*, M^2 of left side, occlusal view; fig. 9, M^2 of right side, occlusal view. Rattlesnake formation, John Day Valley, Oregon.

Fig. 10. *Hyaenarctos sivalensis* Falc. and Caut. M^2, occlusal view, natural size. Siwalik beds, India. (After Lydekker.)

Fig. 11. *Hyaenarctos punjabiensis* Lydekker. M^2, occlusal view, natural size. Siwalik beds, India. (After Lydekker.)

Fig. 12. *Indarctos salmontanus* Pilgrim. M^2 of type specimen, occlusal view, natural size. Siwalik beds, India. (After Pilgrim.)

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Considering that in no. 22362 M^2 is considerably worn, and allowing for individual variation, the resemblances between the Oregon specimen and the type of *I. salmontanus* are close. Small differences, such as the more distinctly circular cross-section of the metacone, the smaller hypocone, slightly longer heel, and wider trigon region in the Oregon form, suggest specific distinction such as would be expected in individuals so widely separated geographically.

The characters of M^2 in the Oregon form, and in *Indarctos salmontanus,* approach those of *Hyaenarctos* excepting in relative elongation of the heel. The two outer cusps of M^2 in *Hyaenarctos* may show somewhat stronger lateral compression than is noted in the Oregon form. The antero-internal ridge in *Hyaenarctos* may apparently show almost no separation into two divisions, or may be very distinctly divided as in *H. palaeindicus,* in which the hypocone region is imperfectly developed. In *H. punjabiensis* (fig. 11) an incipient heel is clearly shown, though it is much less pronounced than in *Indarctos.* As has been suggested by Pilgrim, an intermediate stage between the form seen in *H. punjabiensis* and that in the type of *I. salmontanus* might connect the two groups so closely that generic separation would be difficult if not impossible.

M^2 of the Rattlesnake specimen is distinguished from that of *Arctotherium* by its greater width and much shorter talon. In *Arctotherium* the primitive quadritubercular portion of the tooth is longer anteroposteriorly and the heel is much longer. The arrangement of the tubercles is much the same in the two types, but the tubercles show stronger lateral compression in *Arctotherium.*

The arrangement of the roots supporting M^2 in the Oregon specimen differs somewhat from that in *Arctotherium simum.* In no. 22362 (fig. 8*a*) there are two distinct external roots supporting the paracone and metacone regions. These roots in both available teeth are distinct, but are not widely separated. The inner and posterior regions of these teeth are supported by a large, broad root evidently composed of two parts, one of which supports the protocone region and the other originates above the hypocone and the region behind it.

In *Arctotherium* there are also evidently four original root elements, but the roots beneath the paracone and metacone tend to diverge widely, the element above the metacone being in some cases united with the posterior root supporting the heel. In *Arctotherium* the root supporting the protocone may or may not unite with the root above the heel. In the type of *Indarctos salmontanus* the roots are not exposed.

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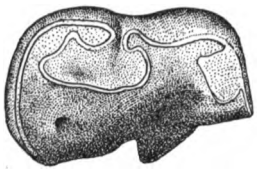
$M_{\bar{2}}$, the only representative of the lower cheek-tooth dentition, is unfortunately so much worn that it illustrates comparatively few characters of the tuberculation (fig. 13). It is distinguished from the corresponding element in the dentition of *Hyaenarctos* and of certain forms of *Arctotherium* by the relative proportions of the trigonid and talonid regions. In the Oregon specimen the anteroposterior diameter of trigonid and talonid are, as nearly as can be determined, approximately equal. In *Hyaenarctos,* as is indicated by the measurements below, the talonid may have an anteroposterior diameter near one-half that of the trigonid. In *Arctotherium simum* the functional talonid may be longer than the trigonid. In some of the South American arctotheres, as in *Pararctotherium enectum*



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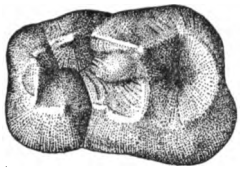

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Fig. 13. *Indarctos(?) oregonensis,* n. sp. $M_{\bar{3}}$, no. 22362, occlusal view, natural size. Rattlesnake formation, John Day Valley, Oregon.

Fig. 14. *Hyaenarctos punjabiensis?* Lydekker. $M_{\bar{3}}$, occlusal view, natural size. Siwalik beds, India. (After Lydekker.)

Ameghino, the proportions are as in *A. simum;* in others, as in *A. wingei* Ameghino, the talonid is relatively short. The increase in length of the heel region in *A. simum* is evidently related to the increase in area of M^2, as the talonid of $M_{\bar{2}}$ articulates with the trigonid portion of M^2.

The tuberculation of $M_{\bar{2}}$ represents only the inner side of the tooth, on which is shown the relatively high region occupied by the metaconid, and the lower more or less basin-like talonid region. The talonid possessed a rather wide hypoconid ridge, and two smaller cusps on the inner border as in *Hyaenarctos.*

The crown of $M_{\bar{2}}$ is supported upon two roots of which the posterior is the larger.

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MEASUREMENTS OF DENTITION

	No. 22362
C, upper, anteroposterior diameter at base of enamel	*a*29.8 mm.
C, upper, transverse diameter at base of enamel	20.0
C, upper, length of root, measured along posterior border	76.7
C, lower, anteroposterior diameter at base of enamel	30.0
C, lower, transverse diameter at base of enamel	*a*21.3
C, lower, length of root, measured along posterior border	73.8
P_1, anteroposterior diameter	12.4
P_1, transverse diameter	7.1

	No. 22362 Left side	No. 22362 Right side	Indarctos salmontanus
P^4, anteroposterior diameter measured along outer side	31.7 mm.	31.0	
P^4, width across deuterocone	22.6	*a*20.9	
P^4, anteroposterior diameter of protocone at base	14.1	13.9	
P^4, anteroposterior diameter of protostyle	4.7	4.6	
M^2, greatest anteroposterior diameter	35.3	35.2	35 (35.5*)
M^2, anterior end of tooth to posterior end of paracone	13.8	14.0	14.8*
M^2, posterior end of paracone to posterior end of tooth	21.5	21.2	20.9*
M^2, anterior end of tooth to middle of metacone	17.8	17.5	19.8*
M^2, middle of metacone to posterior end of tooth	17.5	17.6	15.7*
M^2, width of tooth across paracone	26.8	27.2	27.0
M^2, width of tooth across metacone	24.6	24.0	25.2*
M^2, anterior side of hypocone to posterior end of tooth	17.6	15.6	15.4*
Length of M^2 compared with width of M^2	1.31%	1.29%	1.29%

	No. 22362	A. simum No. 3004	Hyaenarctos punjabiensis?	Hyaenarctos? palaeindicus
$M_{\bar{1}}$, anteroposterior diameter	32.0 mm.	30.4	30.5	30.0
$M_{\bar{1}}$, anteroposterior diameter of trigonid	15.8	14.9	19.0	16.5
$M_{\bar{1}}$, anteroposterior diameter of functional talonid region	16.2	15.5	11.5	13.5
$M_{\bar{1}}$, transverse diameter across talonid	*a*21.3	18.4	19.3	19.2

a, approximate.

* Measurements taken on Pilgrim's figure of M^2.

SKELETAL ELEMENTS

The skeleton of no. 22362 is represented by the greater part of the humerus, half of the ulna, a fifth metacarpal, the navicular and cuboid, a second metatarsal, and several phalanges.

The right *humerus*, the first element of the Pliocene bear to be discovered, is nearly complete. A portion of the distal end had rotted away, and a small part of the proximal end is missing. This

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element (figs. 15*a* to 15*c*) is slightly longer and considerably more massive than that of specimens of *Arctotherium simum* from Potter Creek Cave and from Rancho La Brea. This difference between the Oregon form and the California Pleistocene *Arctotherium* is well shown in transverse diameter and thickness of the narrowest portion of the shaft at the lower end of the pectoral ridge. The supinator ridge is strongly developed as in *A. simum*, and is higher or wider than in either the Potter Creek Cave or the Rancho La Brea specimens. The flat area between the deltoid and pectoral ridges is more strongly marked and wider than in the California Pleistocene *Arctotherium* specimens. The lower end of this area also extends relatively much nearer the distal end of the shaft than in *A. simum*, and in side view (fig. 15*c*) is seen to project farther anteriorly. A large entepicondylar foramen is present as in *Arctotherium*. The bar of bone forming the outer boundary of this foramen is largely broken away, but the remaining portion appears relatively heavier than in *Arctotherium*. The upper end of the foramen seems more broadly rounded than the superiorly narrowed foramen in *A. simum*.

On the whole the humerus is of a much more massive type than that of the California *Arctotherium*, and in this respect suggests the relatively heavy skeletal elements of *Hyaenarctos*.

The proximal half of the right *ulna* (figs. 16*a* and 16*b*) resembles in many respects the corresponding element of *Arctotherium simum*, but it is much larger and more massive than the California Pleistocene specimens. The anteroposterior diameter or greater width of the shaft seems relatively longer in no. 22362 than in the *Arctotherium* of California, and one might assume that in the Pliocene form this element was relatively somewhat stronger and heavier. The olecranon region of no. 22362 is longer than in *A. simum* and the anterior tuberosity of the olecranon is considerably higher. The posterior region of the olecranon is sharply twisted toward the inner side as in *Ursus* and *Arctotherium*. The anterior tuberosity is separated from the twisted posterior angle of the olecranon by a sharply marked concave surface which is not represented on the olecranon in *Arctotherium* and *Ursus*. The greater sigmoid cavity is deep and the lesser sigmoid cavity is distinctly concave.

In no. 22362 the ulna differs from a specimen described as *Hyaenarctos* from the Siwaliks of the Saharanpur district by Lydekker.[3] The Indian specimen was assumed by Lydekker to represent *Hyaen-*

[3] Lydekker, R., Records, Geol. Survey of India, vol. 21, part 4, p. 145, 1888.

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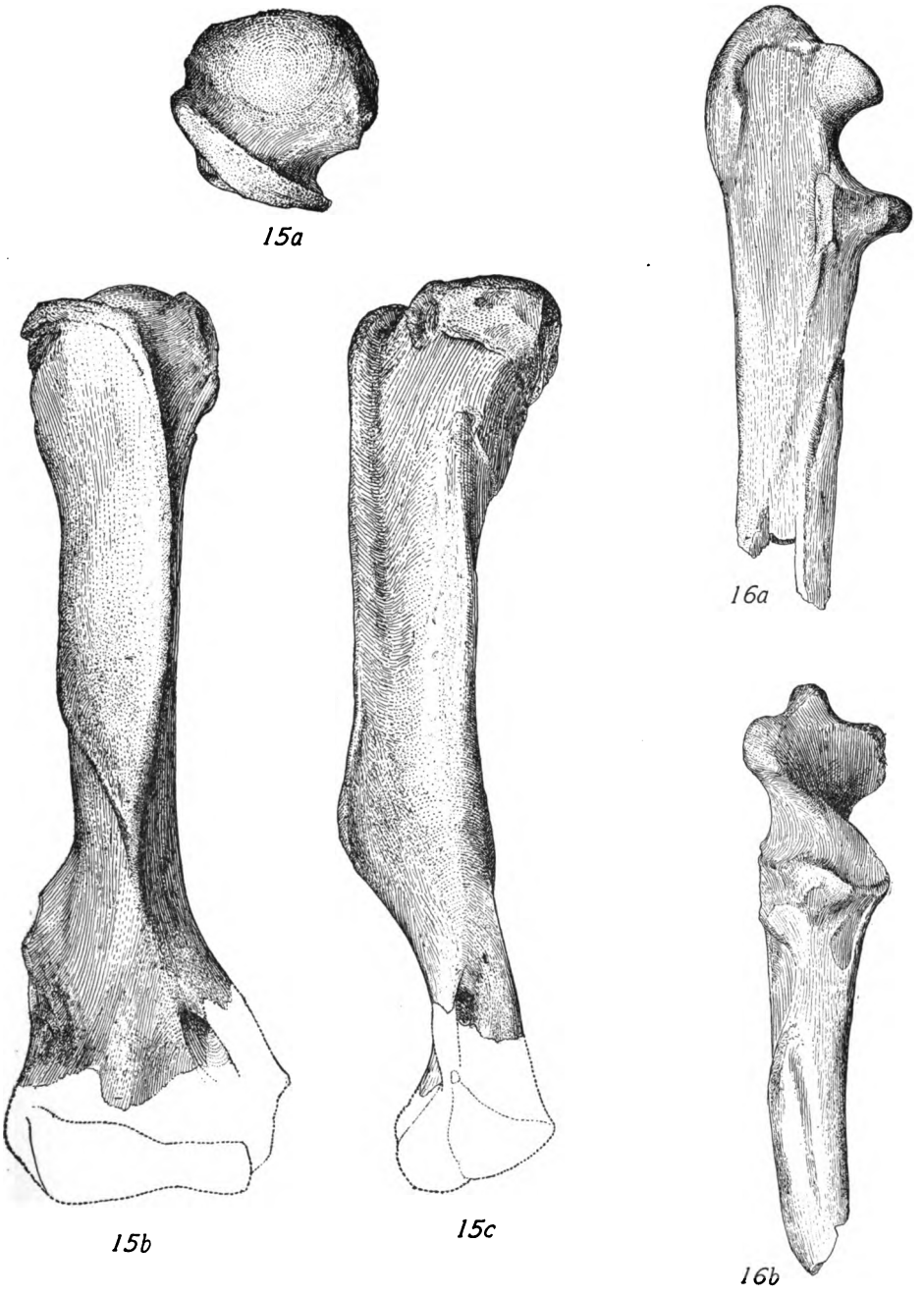

Figs. 15*a* to 16*b*. *Indarctos(?) oregonensis*, n. sp. Humerus and ulna, no. 22362, × ¼. Fig. 15*a*, humerus, proximal view; fig. 15*b*, humerus, anterior view; fig. 15*c*, humerus, inner view. Fig. 16*a*, ulna, outer view; fig. 16*b*, ulna, anterior view. Rattlesnake formation, John Day Valley, Oregon.

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arctos, although not found with other material representing that genus. It shows a somewhat longer olecranon, and a much more prominent anterior tuberosity than appears in the Oregon specimen. The anterior tuberosity is also nearer the proximal border of the greater sigmoid cavity in the Indian form. Lydekker called attention to the similarity of the Indian specimen to the ulna of *Amphicyon.*

Metacarpal 5 (figs. 17*a* to 17*d*) resembles in general the form of this element in the bears, especially that in *Arctotherium.* The Oregon specimen differs greatly in proportions from *A. simum* and *A. californicum* of the California Pleistocene. In no. 22362 this element has almost exactly the same length as specimen 3040 representing *A. simum* from Potter Creek Cave, but is very much thicker and heavier than the Potter Creek Cave specimen. The thickness of no. 22362 approximates that in the type of *A. californicum* from the Pleistocene of Rancho La Brea, but the shaft in the Rancho La Brea specimen is much longer and more slender. The Oregon specimen differs from the known California arctotheres in details of structure of metacarpal 5 as well as in proportions. In no. 22362 the distal articulation is more strongly bulbous on the superior side, and the median inferior keel is thicker and decidedly more prominent at the posterior end. At the distal end of the superior surface of the shaft there is a marked depression immediately posterior to the bulbous distal articulation, whereas in the California arctotheres this area may be flat rather than concave as in no. 22362. Also at the distal end of the inferior surface of the shaft there is a distinct concavity in the Oregon specimen, while in *A. simum* and *A. californicum* this region tends to be convex. In the middle of the superior surface of the shaft no. 22362 is strongly convex along the anteroposterior contour, while in the California *Arctotherium* specimens this outline is nearly straight. The proximal articular face of no. 22362 is narrower transversely than in either *A. simum* or *A. californicum.*

The specimen representing *metatarsal 2* (figs. 18*a* and 18*b*) is not as well preserved as the fifth metacarpal, and less satisfactory material of *Arctotherium* is available for comparison. In this metapodial, as in metacarpal 5, the tendency is toward somewhat greater thickness than in *Arctotherium,* but the element does not appear relatively as short compared with the corresponding element of *Arctotherium* as is the case in metacarpal 5. At the distal end the keel is somewhat more prominent than that in a specimen of *A. simum* from Potter Creek Cave.

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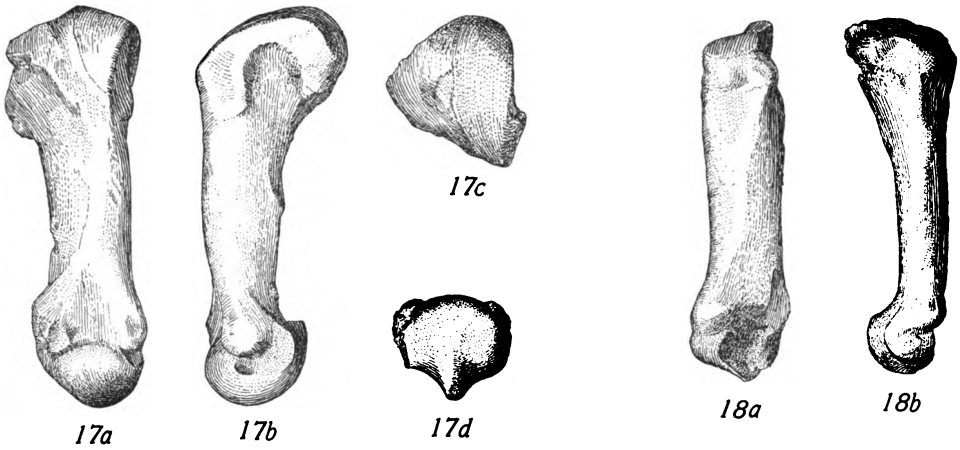

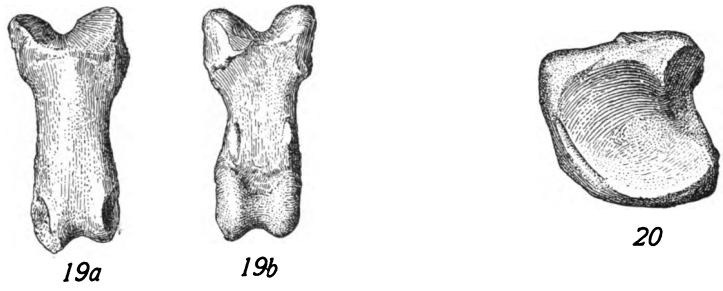

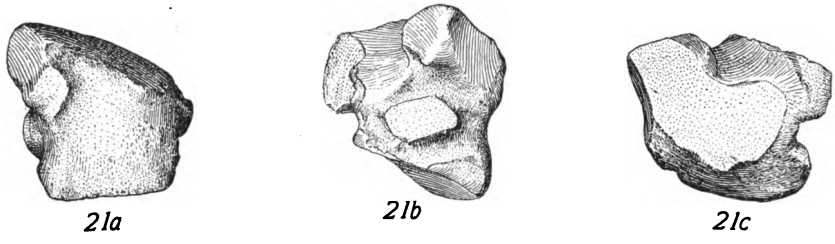

Figs. 17*a* to 21*c*. *Indarctos(?) oregonensis*, n. sp. No. 22362, × ½. Fig. 17*a*, metacarpal 5, dorsal view; fig. 17*b*, metacarpal 5, median view; fig. 17*c*, metacarpal 5, proximal view; fig. 17*d*, metacarpal 5, distal view. Fig. 18*a*, metatarsal 2, dorsal view; fig. 18*b*, metatarsal 2, inner view. Fig. 19*a*, phalanx 1, dorsal view; fig. 19*b*, phalanx 1, ventral view. Fig. 20, navicular, proximal view. Fig. 21*a*, cuboid, dorsal view; fig. 21*b*, cuboid, median view; fig. 21*c*, cuboid, proximal view. Rattlesnake formation, John Day Valley, Oregon.

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A *navicular* (fig. 20) of the left foot is somewhat larger than the corresponding bone in the specimen of *A. simum* from Potter Creek Cave. The differences in the form of the element are not large. Although the navicular in no. 22362 is noticeably broader than the corresponding tarsal element in *Arctotherium* from Potter Creek Cave, it has approximately the same depth. In the Pliocene specimen the facet for the astragalus is not as deeply concave as that in *Arctotherium*. The ventral portion of the articulating surface for the cuboid is larger and truncates the lateral margin more acutely than in the latter genus. Along the external border of the navicular this surface is less extensive than in *Ursus*. The union of the median and ventral borders is less distinctly rounded than in *A. simum*. The distal articulating surface is obscurely divided for the cuneiform elements. The ventral tubercle is large.

The *cuboid* (figs. 21*a* to 21*c*) possesses a long inner side and approaches more nearly a cuboidal form than does the corresponding element in the Recent *Ursus*. The cuboid of the Pleistocene *Arctotherium* from Potter Creek Cave is in this regard intermediate between that of no. 22362 and *Ursus*. In contrast to *Arctotherium* the angle between the dorsal plane and the plane of the metatarsal facet in the Pliocene cuboid is less acute.

The larger cuboid facet for the navicular is subtriangular. It is separated from an inner facet for the astragalus by a right angle, and is directed decidedly toward the ventral side. In *Arctotherium* and in *Ursus* this surface is directed more toward the inner side of the cuboid and is separated from the astragalar facet by an obtuse angle. The distal end of the boundary between the navicular and astragalar facets is truncated by a very small articulating surface also for the navicular. The latter has a greater dorso-ventral extent in *Arctotherium*.

The concave cuboid facet for the astragalus differs in its greater size and rectangular form from that in *Arctotherium* and in the Recent *Ursus*. Distal to this facet and widely separated from it is a large and flat articulating surface for the external cuneiform. In *A. simum* this surface is broadly confluent with the navicular facet. It is situated farther to the ventral side in no. 22362 than in the cuboid of *A. simum*. Only a single facet articulates with the external cuneiform at the distal margin of the cuboid.

The metatarsal facet of the cuboid is triangular and relatively smaller than in *Arctotherium*. On the ventral side of the cuboid the transverse ridge is situated farther proximally, especially toward the

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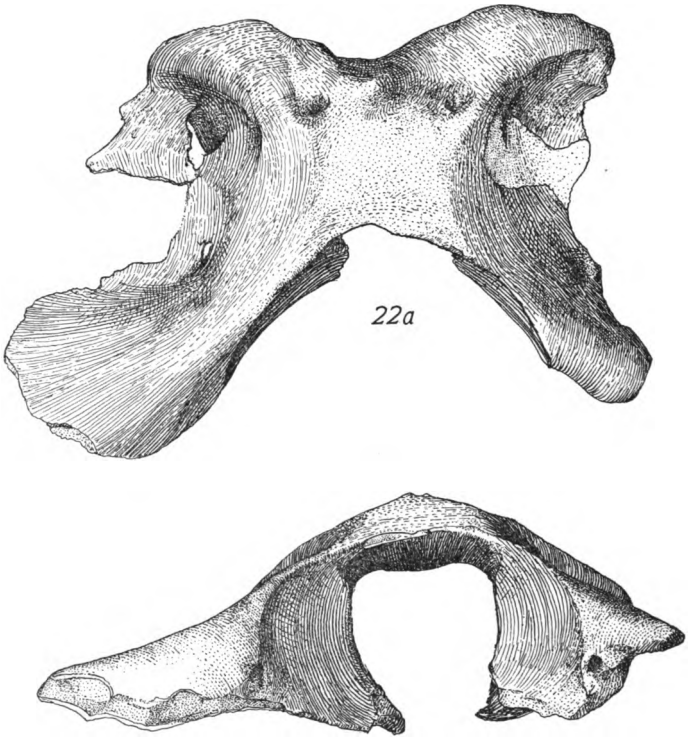
outer end, and the inner end is not as thick as in *Arctotherium*. The peroneal groove is much deeper than in either *Arctotherium* or *Ursus*, indicating a well developed peroneal muscle.

Two *phalanges* of the proximal series were recovered. One of the specimens (figs. 19*a* and 19*b*) is much longer than the other. They are both much larger than the first phalanges in *Ursus* and *Arcto-*



Figs. 22*a* and 22*b*. Atlas associated with type specimen of *Indarctos(?) oregonensis*. No. 22362?, × ½. Fig. 22*a*, dorsal view; fig. 22*b*, posterior view. Rattlesnake formation, John Day Valley, Oregon.

therium simum under observation. Both are noticeably compressed dorso-ventrally, as is the bears. The distal end is flexed downward, giving a distinct longitudinal arch to the dorsal surface. The proximal extremity is relatively broad and its ventral border is deeply notched.

An *atlas* (figs. 22*a* and 22*b*) found associated with rib fragments near the locality of no. 22362 represents a very large carnivore with

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characters differing from those of *Arctotherium,* the true bears, and such other carnivores as would be expected to occur in this formation. The atlas is much larger than that of an *Arctotherium* specimen from Potter Creek Cave, and differs from it structurally in several particulars. The lateral wings are broken, but seem to have been broad and to have extended with a wide sweep posteriorly somewhat as in *Ursus.* The posterior portion of the lateral wings extends behind the facets for articulation with the axis, as in *Smilodon,* without an interruption or notch such as appears in *Arctotherium, Ursus,* the dogs, and the true cats. In the specimen found near no. 22362 the extension of the wings behind the axis facets is buttressed by a high superior ridge which runs across the region in which the notch would be situated in the true bears or in *Arctotherium.* In this particular this atlas is again similar to that of *Smilodon.* One of the most important characters is found in the position of the vertebrarterial foramen, which in the Pliocene specimen is situated low down at the posterior border of the lateral wings, and immediately behind the facets for the axis. This situation is much as in *Smilodon.* In *Ursus* the posterior opening of this foramen is situated high up on the posterior side of the lateral wings. In *Arctotherium* it is situated considerably in advance of the postero-superior border of the wings. The position of this foramen in *Arctotherium* resembles more closely that of the dogs than in the case of *Ursus.*

The atlas from the Rattlesnake differs from that of the cats and the dogs in that the passage for the vertebral artery through the anterior side of the lateral wings is in an enclosed foramen instead of in a groove or notch in the anterior border. In this respect this atlas resembles that of *Ursus* and *Arctotherium.*

The characters of the atlas found near no. 22362 resemble those of the bears in the nature of the anterior portion of the vertebrarterial passage, resemble the cats in the nature of the posterior extremity of this canal, and resemble *Smilodon* in the form of the posterior border of the lateral wings. It is interesting to note that, whereas the atlas of *Arctotherium* is in certain respects more dog-like than that of *Ursus,* the Rattlesnake specimen differs widely from the dogs in the particular characters in which *Arctotherium* approaches them, and in these characters the Rattlesnake form resembles *Smilodon* more closely.

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MEASUREMENTS OF SKELETAL PARTS

	No. 22362
Humerus—	
Length from head to radial articulating surface	*a*490 mm.
Anteroposterior diameter of head	*a*122
Transverse diameter of head at tuberosities	*a*108.3
Anteroposterior diameter of shaft at distal end of deltoid crest	81.4
Least transverse diameter of shaft	53.6
Width of distal end	*a*158
Ulna—	
Distance from proximal end of greater sigmoid cavity to end of olecranon	80.3
Greatest anteroposterior diameter at coronoid	98.6
Greatest transverse diameter of shaft distal to greater sigmoid cavity	38.4
Metacarpal 5—	
Greatest length	103.6
Greatest anteroposterior diameter of proximal end	39
Transverse diameter of proximal end	*a*32.4
Transverse diameter at middle of shaft	21.5
Transverse diameter of distal end	*a*30
Metatarsal 2—	
Greatest length	94
Anteroposterior diameter of proximal end	*a*28.2
Transverse diameter of proximal end	*a*18.3
Transverse diameter at middle of shaft	18
Anteroposterior diameter at middle of shaft	12.8
Navicular—	
Greatest width	44.2
Greatest depth	46
Cuboid—	
Greatest proximo-distal diameter	40.4
Greatest transverse width	*a*49.4
Depth of metatarsal facet	36.8
Width of metatarsal facet	34.2
Phalanx 1—	
Greatest length	61.2
Width of proximal end	28.8

a, approximate.

RELATIONSHIPS

Although the representation of dentition and skeleton of the Oregon Pliocene bear is scanty, the elements available for study are fortunately among the most important that could be selected for comparative study. In the dentition the second upper molar and the upper carnassial have larger significance than all other members of the dental series for the particular comparison before us.

The broader relationships of the Rattlesnake bear are as clearly shown by M^2 and P^4 as they could be by M_1, while the greater varia-

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bility of these two upper teeth tells the story with more detail and gives expression to the closer affinities. The few skeletal elements present, though leaving much to be desired, show characters of high value in estimating the more intimate relationships of this form.

The Oregon Pliocene bear approximates the characters of *Indarctos salmontanus* Pilgrim in the structure of M^2, the only available tooth representing that genus. The characters seen in the type of *Indarctos* and in the Oregon specimen are not found in other known forms. These characters are most nearly approached in M^2 of *Hyaenarctos, Arctotherium,* and *Aeluropus;* and are intermediate between those of *Hyaenarctos* and *Arctotherium.* In the characters of P^4 the Oregon specimen does not differ essentially from the several known species of *Hyaenarctos,* but is distinctly different from *Arctotherium, Aeluropus,* and all other known forms referred to the bear group.

If as is indicated by the characters of M^2 the Oregon form belongs to the same general group of bears as *Indarctos salmontanus,* and shows approximately the same stage of evolution, it seems probable that the Siwalik *Indarctos* also possessed the *Hyaenarctos* type of P^4. From slender evidence furnished by strength of the maxilla and form of a small portion of the posterior border of the alveolus of P^4, Pilgrim[4] inferred that P^4 of *I. salmontanus* was large and possessed a distinct inner root; and that its inner cusp or deuterocone did not occupy an extreme posterior position as in *Helarctos,* in all modern bears, and in the Pliocene and Pleistocene types referable to *Ursus.* With such evidence as is at hand it may be assumed that P^4 of Pilgrim's *Indarctos* was not materially different from that in the Oregon specimen.

The characters of the massive limb elements of the Oregon specimen, so far as they are known, suggest the limb type of *Hyaenarctos,* and indicate a rather wide separation from *Arctotherium.*

The sum of the known characters of the Oregon bear, specimen 22362, represent a type near *Hyaenarctos,* but tending toward *Arctotherium* in the development of its last upper molar. The Oregon form cannot be sharply separated from the Siwalik type of *Indarctos* on the basis of available material. Differences in proportions of the tubercles of M^2 suggest the specific divergence which is to be expected in forms found in regions so widely separated geographically as India and Oregon. The Oregon form may be referred tentatively to the genus *Indarctos* with the specific name *oregonensis.*

[4] Pilgrim, G. E., Records, Geol. Surv. India, vol. 44, part 3, p. 230, 1914.

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The *Indarctos* group is nearer to *Hyaenarctos* than to *Arctotherium,* and as suggested by Pilgrim[5] the discovery of a type intermediate between *Hyaenarctos punjabiensis* and *Indarctos salmontanus* might make it difficult to establish a generic separation between *Indarctos* and *Hyaenarctos.*

The occurrence in the Oregon Pliocene of a form closely allied to an Indian Siwalik type suggests close faunal relationship of Asia and North America in early Pliocene time. The presence of a form of the *Hyaenarctos* type with characters tending toward those of *Arctotherium* in the North American Pliocene also gives support to the assumption that the American *Arctotherium* is derived from a line passing near that of *Hyaenarctos.* It is now possible to consider the origin of *Arctotherium* in America rather than in Eurasia. As no bears of the *Ursus* type are known from the Pliocene of America, we may conceive of *Arctotherium* as originating in North America in the Pliocene and entering South America before *Ursus* was present in the New World. This would account for the large Pleistocene development of *Arctotherium* in South America in absence of *Ursus,* though the two groups appear together in the North American Pleistocene.

A large lower carnassial of a bear-like animal (figs. 23*a* and 23*b*) from the brown coal of Tehuichila near the boundary between the states of Hidalgo and Vera Cruz, Mexico, was thought by Freudenberg[6] to resemble *Hyaenarctos.* This specimen was found in beds containing a *Hipparion* fauna, and presumed to be of upper Miocene or lower Pliocene age. An excellent cast of the Mexican specimen kindly furnished by Dr. Freudenberg is available for comparative study. This tooth resembles in many respects the lower carnassial of a specimen referred to *Hyaenarctos punjabiensis* by Lydekker.[7] The general form of both the trigonid and talonid portions of the tooth is like that of *Hyaenarctos,* and the proportions compared in antero-posterior diameter are approximately the same. Unfortunately the Mexican specimen is broken in the region of the metaconid, but as nearly as can be determined this portion of the tooth may not have been widely different from that of the Indian genus.

The occurrence of the specimen from Tehuichila is presumably at a horizon not widely removed from that of the Rattlesnake Pliocene

[5] Pilgrim, G. E., *op. cit.,* p. 227, 1914.

[6] Freudenberg, W., Geol. u. Palae., Abh. N. F., Bd. 9, p. 13, 1910.

[7] Lydekker, R., Mem. Geol. Surv. India, ser. 10, vol. 2, pl. 31, fig. 1, 1884.

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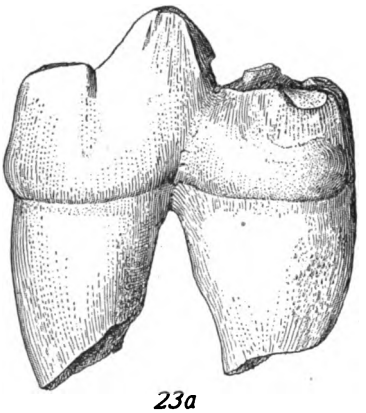
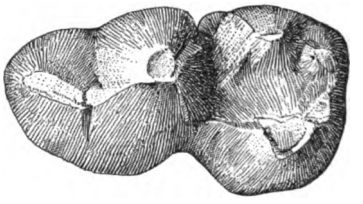
of Oregon, and there can be little doubt that, as suggested by Freudenberg, the form represents the general group of *Hyaenarctos*. The closer relationships can hardly be determined with certainty, but it is of great interest to note that this group is represented in beds of approximately lower Pliocene or late Miocene age in Mexico, adjacent to the South American region, in which the arctotheres were so largely developed in the Pleistocene.



23a



23b

Figs. 23*a* and 23*b*. *Hyaenarctos* or *Indarctos*. $M_{\bar{1}}$, natural size. Fig. 23*a*, outer view; fig. 23*b*, occlusal view. From late Cenozoic deposits, Tehuichila, Mexico. (Drawn from cast furnished by Dr. W. Freudenberg.)

Two forms from South America described by Ameghino as *Pararctotherium* and *Proarctotherium* have been assumed to be ancestral types of the South American arctotheres. *Pararctotherium* is known from the Pampean formation, which corresponds to a considerable portion of the Pleistocene of North America. *Pararctotherium* is clearly a member of the *Arctotherium* group in which $M_{\bar{2}}$ is considerably specialized. The anterior premolars of *Pararctotherium* are crowded, and the facial region was evidently shortened. There is no good reason for considering that this type is ancestral to *Arctotherium;* in fact, it may be one of the more specialized members of the *Arctotherium* group.

Proarctotherium is known from a very fragmentary specimen consisting of $M_{\bar{2}}$ and $M_{\bar{3}}$ from Parana. The Parana deposits have been assumed to be Pliocene, and may contain a small number of North American Pliocene types. Ameghino's[8] figure of the type specimen

[8] Ameghino, F., Contribucion al conocimiento de los mamiferos fosiles de la Republica Argentina, p. 319, pl. 21, fig. 1, 1889.

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shows a $M_{\bar{2}}$ not differing materially from that of *Arctotherium*. $M_{\bar{3}}$ is large and elongate, approximating the form seen in typical Pleistocene *Arctotherium*, as in *A. simum*.

The type specimen of *Proarctotherium* evidently represents a typical member of the *Arctotherium* group. As the occurrence of a representative of the *Hyaenarctos* type seems now fairly established for the late Tertiary of Mexico, it is of course possible that a member of the group reached South America with the earliest of the Pliocene-Pleistocene emigrants from North America. While the characters of $M_{\bar{2}}$ in the Parana form do not differ greatly from those of *Hyaenarctos*, $M_{\bar{3}}$ is of a distinctly more advanced type. The nature of the specialization of $M_{\bar{3}}$ is such as we commonly find associated with an anteroposteriorly elongated heel of the last upper molar, and is not to be expected in a Pliocene bear. Apparently the geologic occurrence of the Parana specimen must remain in doubt until other material of this nature appears in the Parana.

Transmitted October 25, 1916.

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BY

JOHN C. MERRIAM

MAMMALIAN REMAINS FROM A LATE TERTIARY FORMATION AT IRONSIDE, OREGON

BY

JOHN C. MERRIAM

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MAMMALIAN REMAINS FROM THE CHANAC FORMATION OF THE TEJON HILLS, CALIFORNIA

BY
JOHN C. MERRIAM

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INTRODUCTION

Within a few weeks following the publication of a note[1] on mammalian remains from the Tejon Hills of California, in 1915, a party representing the Department of Palaeontology of the University of California visited the Tejon Hills, at the request of the writer, to secure additional material, and to make further study of the occurrence of the fauna. This party, consisting of J. P. Buwalda, B. L. Clark, and F. E. Vaughan, examined the Tejon Hills area in which the first material was found and re-studied with care the beds from

[1] Merriam, J. C., Remains of land mammals from marine Tertiary beds in the Tejon Hills, California, Univ. Calif. Publ., Bull. Dept. Geol., vol. 8, pp. 283–288, 1915.

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which R. W. Pack of the United States Geological Survey, and later R. H. Stoner of the University of California, secured the interesting mammalian remains described in 1915.

For important mammalian material secured, and for additional data concerning the sequence of formations and occurrence of mammalian remains, the writer is much indebted to the party visiting the Tejon Hills area in 1915. Reports on the geologic occurrence furnished by members of the 1915 party are given in full in the discussion of stratigraphic position following.

STRATIGRAPHIC POSITION OF MAMMAL-BEARING CHANAC FORMATION IN THE TEJON HILLS

As noted in the earlier publication[2] on the Tejon Hills fauna, difference of opinion has existed concerning the formation sequence and the age of the deposits containing mammalian remains obtained in this area. The geologic section has not been easily understood, and age determination could not readily be made without fuller information as to invertebrate faunal sequence of the Pacific Coast Province than was at hand at the time of the first examination of the Tejon Hills region. In the earlier studies there seemed good reason for considering that remains of land mammals were found in strata containing a marine invertebrate fauna comparable to that of beds of the Temblor Range referred to Lower Miocene. Other opinion suggested tentatively the "Santa Margarita" or late Miocene age of the mammal-bearing formation.

With the evidence available at the time of publication of the earlier paper[3] the writer concluded that intensive study of the invertebrate fauna of the Tejon Hills would be necessary before a fully satisfactory correlation with other marine Tertiary formations of the San Joaquin Valley could be made, and expressed the view that faunas of both "Santa Margarita" and "Temblor" stages might be represented in the section.

As is stated in the reports by Dr. Buwalda and Dr. Clark given below, the work of the 1915 party points toward the existence of three divisions or three formations in the geologic section of the Tejon Hills. The divisions reported are: (1) marine "Temblor" or Monterey, generally considered as Lower Miocene; (2) marine "Santa Mar-

[2] Merriam, J. C., *op. cit.*, 1915.

[3] Merriam, J. C., *op. cit.*, pp. 284 and 285, 1915.

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garita," considered as Upper Miocene; and (3) an alluvial or freshwater formation described as the "Chanac" by Dr. Buwalda. An unconformity is reported to occur between "Temblor" and "Santa Margarita." The Chanac formation is later than the "Santa Margarita" and is presumed to be unconformable upon it, but the evidence is not complete on this point.

The 1915 party found remains only in beds of the uppermost or Chanac formation, though they occurred at localities in close proximity to marine beds.

Following are the statements as to geologic sequence and occurrence of mammalian fauna by Dr. Buwalda and Dr. Clark:

NOTE ON THE GEOLOGY OF THE TEJON HILLS, FURNISHED BY J. P. BUWALDA

The Tejon Hills occupy an area about seven miles long in a north-south direction and about three miles wide, on the eastern side of the southern end of the San Joaquin Valley. They rise to heights of six hundred to eight hundred feet above the floor of the valley, and present a subdued topography.

The section in the Tejon Hills contains three Tertiary formations. The lowermost is a series of sandstones and conglomerates considered by Dr. B. L. Clark to be of Monterey age (Vaqueros or Temblor, marine Lower Miocene). Overlying these strata unconformably is a formation considered by Dr. Clark to be the equivalent of the "Santa Margarita" (marine Upper Miocene). The uppermost formation is a terrane which is apparently of terrestrial origin.

The Monterey is exposed over an area about two and one-half miles in length between Comanche Creek and the escarpment of old crystalline rocks of the Sierra Nevada. It lies on an eroded surface of the crystalline rocks and is not faulted against them. The formation consists of dark gray and yellow sandstones. It is often conglomeratic, and is usually rather coarse and massive. Conglomerate beds occur especially in the upper and lower parts of the formation. The pebbles and boulders are usually quartz and are well waterworn. The thickness is estimated at about three hundred feet. The formation dips gently toward the west and away from the crystalline rocks. It contains a marine fauna determined by Dr. B. L. Clark as Lower Miocene.

In the northern end of the Tejon Hills, strata of distinctly different character overlie the Monterey just described and extend up on the crystalline rocks. They are exposed over an irregular area about two miles in diameter around the lower portion of Comanche Creek. These beds consist of strikingly white and cream-colored quartzose

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sandstones and gravels, and clay strata. The sandstones are coarse and the grains exhibit markedly the effects of water wear. The conglomerate pebbles and boulders are well rounded and polished. The formation has a thickness of perhaps one hundred feet. These beds lie with marked unconformity upon the Monterey and contain a marine fauna determined by Dr. Clark to be the "Santa Margarita" stage of the upper Miocene. At the northern end of the area these beds have been more sharply deformed than the Monterey where it is known in this area, so that they dip away from the crystalline rocks at angles of 25 degrees or more.

The uppermost stratigraphic member in the Tejon Hills extends from the northwest end of the hills over almost the entire remaining territory excepting a small area of crystalline rocks exposed at the point where Tejon Creek enters the hills, and along Chanac Creek. Areally this uppermost member is the most important terrane of the Tejon Hills. In view of their distinctiveness in lithologic character and in mode of origin the name Chanac formation is proposed for these strata. Lithologically this formation consists of angular sands and coarser angular materials. The particles are mainly rhyolitic and display white, yellow and striking reddish-brown colors in exposures. The materials are not well classified as to size and are not sharply bedded. Their characters are altogether those of a terrestrial deposit of the alluvial fan type, and they should be termed fanglomerates. Their thickness is estimated to be four hundred to six hundred feet. The Chanac fanglomerates rest upon both of the older Tertiary formations and in the southern part of the Tejon Hills upon the old crystalline rocks. From the geologic evidence it seems probable that they bear an unconformable relation to the beds they overlie, but the evidence does not appear conclusive. The distinctly different character of the materials and of the faunas of the Chanac contrasted with the underlying formations, indicates a change from marine conditions to the terrestrial conditions, and favors the view of unconformity. Theoretically, such changes might be the result of the filling of a marine basin and the deposition, without interruption, of terrestrial beds upon the marine strata. The areal relations, however, suggest unconformity, although no discordance was observed in the attitude of the strata of the Chanac and "Santa Margarita," and no pre-Chanac surface of erosion.

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NOTE ON THE MARINE TERTIARY FAUNAS OF THE TEJON HILLS SECTION, FURNISHED BY B. L. CLARK

Marine deposits of the two stages of the Miocene are represented in the Tejon Hills. A number of characteristic species of that phase of the Miocene generally known as the Monterey of the local phase designated as Vaqueros or Temblor are represented in gray and brown sandstone, having a thickness of about 300 feet. These beds rest unconformably upon the granite and have a dip of from 10 degrees to 15 degrees. Certain of the species found in this formation are generally considered characteristic fossils of the Monterey group. Among these forms may be listed the following:

Scutella andersoni Twitchell
Scutella merriami Anderson
Pecten andersoni Arnold
Leda ochsneri Anderson and Martin
Oliva californica Anderson
Trophon kernensis Anderson
Conus oweniana Anderson
Terebra cooperi Anderson
Turritella ocoyana Conrad

Disconformably overlying the Vaqueros or Temblor of the Tejon Hills is the Santa Margarita Upper Miocene. The beds of this formation are best exposed near the mouth of Comanche Creek. Here they have a thickness of between 50 and 100 feet. They are generally composed of light-colored arkose sandstones with which occur lenses of clay and gravel. The fauna found in these beds apparently belongs to the Astrodapsis whitneyi zone as recognized in the San Pablo group of the Mount Diablo region, and to the same horizon as the Santa Margarita beds to the north of Coalinga. The following species were collected from the Santa Margarita of the Tejon Hills on the west side of Comanche Creek near the western boundary of the NW ¼, sec. 13, T 32 S, R 29 E, M. D. B. and M.

Dosinia arnoldi Clark
Metis alta (Conrad)
Ostrea titan Conrad
Ostrea, cf. vespertina Conrad
Pecten crassicardo Conrad
Pecten crassicardo, n. var.
Pecten hastatus Sowerby
Pecten raymondi Clark
Phacoides richthofeni (Gabb)
Phacoides sanctaecrucis Arnold
Pinna alamedensis Yates
Piteria stalderi Clark
Saxidomus nuttali Conrad
Siliqua, cf. lucida (Conrad)
Venus pertenuis Gabb
Bulla, sp.
Calyptraea, sp.
Conus, sp.
Fusinus, n. sp.
Nassa pabloensis Clark
Natica, sp.
Shark teeth

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COMPOSITION AND RELATIONSHIPS OF MAMMALIAN FAUNA OF THE CHANAC FORMATION

The representation of mammalian forms obtained in the land-laid beds of the Chanac formation is very scanty, but it includes more and better preserved material than that upon which the first note was based. Following is a list of the forms now available:

Rhinocerotid, indet.
Protohippus tehonensis Merriam.
Neohipparion gratum tehonense Merriam
Neohipparion, near molle Merriam.
Prosthennops, sp.
Camelid, indet. large.
Merycodus, near necatus Leidy.
Proboscidean (Tetrabelodon?), indet.

The general aspect of the small assemblage of forms now known is not materially different from that originally suggested. It is clear, however, that the most commonly encountered horses of this fauna represent the genus *Hipparion*. The best-known teeth are those of two small forms, *Neohipparion gratum tehonense,* closely resembling *Neohipparion gratum* of the Great Plains region; and a form closely approaching *Neohipparion molle* found in the lower portion of the Jacalitos-Etchegoin Pliocene section of the North Coalinga region. Horses closely resembling those of the Tejon Hills region have been found by R. W. Pack in late Tertiary beds on the eastern flank of the Mount Diablo Range, southwest of Modesto. Of the Hipparion-like horses known in the faunas of the Mohave Desert region, the type most closely approaching the Tejon Hills form is found in an undescribed species obtained in the upper portion of the Ricardo Pliocene section. The Ricardo form does not, however, seem to be specifically identical with that from the Tejon Hills. The Tejon Hills horse described as *Protohippus tehonensis* has some resemblance to a form found in the upper Miocene Barstow formation of the Mohave Desert, but seems not to be specifically identical with the Barstow form. The Tejon Hills *Protohippus* also shows similarity to a species known in the lower portion of the Jacalitos-Etchegoin section of the North Coalinga region.

The rhinocerotid and mastodontine remains from the Tejon Hills furnish no definite evidence as to age. Rhinoceroses are well represented in the Thousand Creek and Rattlesnake Pliocene of Nevada and Oregon, and are known in the Pliocene of the Pinole Tuff type section in San Francisco Bay region of California. It is interesting to note that as yet no remains of rhinoceroses have been secured from

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any of the four Cenozoic faunas of the Mohave Desert. It is possible that they are present in both the Barstow and Ricardo, but have not been recognized. Abundant material is, however, available from both Barstow and Ricardo with no recognized remains of rhinoceroses, while both of the exceedingly scanty collections from the Tejon Hills have included fragments of rhinoceros teeth. The rhinoceros group possibly avoided the peculiar habitat of the Mohave Desert, and may have existed in the California province west of the main divide during the period in which Miocene and Pliocene formations were being deposited in the Mohave area.

The *Merycodus* and camel remains of the Chanac fauna are not sufficiently characteristic to give us a determination of the relationship of the Tejon Hills assemblage to that of the Barstow and Ricardo. The single *Merycodus* tooth is very close in its form and dimensions to teeth from the Ricardo, and may represent the same species. The *Merycodus* horn fragments are not to be distinguished from types represented in both the Barstow and Ricardo faunas.

The available evidence furnished by the Chanac mammalian fauna indicates that it represents a stage older than the Pliohippus proversus zone of the Upper Etchegoin in the North Coalinga region, and later than the Barstow, the youngest recognized Upper Miocene of the Pacific Coast and the Great Basin provinces. The Chanac is evidently of an early Pliocene or latest Miocene phase. It is presumably nearest to the faunas of the lower portion of the Jacalitos-Etchegoin of the North Coalinga region and to the Ricardo stage of the Mohave area.

DESCRIPTION OF CHANAC MAMMALIAN FAUNA

RHINOCEROTID AND MASTODONTINE REMAINS

In the earlier discussion of the Tejon Hills fauna a fragment of a large tooth,[4] at first assumed to represent a proboscidean, was tentatively considered as a member of the Rhinocerotidae, as the structure of the outer wall closely resembled that of rhinoceros tooth forms. In the collection obtained in 1915 a portion of a large rhinoceros lower cheek-tooth furnishes satisfactory evidence of the presence of this group in the Chanac fauna. This tooth fragment, no. 22368, represents a large animal of uncertain systematic position. The presence of a rhinoceros in the Tejon Hills fauna is a matter of consider-

[4] Merriam, J. C., *op. cit.*, fig. 6, 1915.

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able interest, as no remains representing the Rhinocerotidae have been recognized in either the Barstow or the Ricardo fauna. A calcaneum representing a member of this group is known in the fauna of the Pinole Tuff Pliocene of middle California, and the group has been reported from the Thousand Creek and Rattlesnake Pliocene of northern Nevada and Oregon. It is possible that in late Tertiary time this group did not range into the Mohave Desert area.

NEOHIPPARION GRATUM TEHONENSE, n. subsp.

Type specimen, no. 21780, from the Chanac formation of the Tejon Hills at the southern end of the San Joaquin Valley, California.

This species corresponds approximately in size and form to *Neohipparion gratum* of the Great Plains region. It is doubtfully distinguished from the typical form of that species by the tendency to show a more nearly circular cross-section of the protocone and by somewhat dubious characters in width of crown and nature of the enamel folds bordering the fossettes.

The character of the protocone of the Chanac form (figs. 1*a* to 1*c*) suggests *Hipparion plicatile* of the Alachua clays of Florida, but the crowns in that species seem larger and relatively wider than in the Chanac species. *H. ingenuum* also of the Alachua clays is not widely removed from the Chanac species, but the protocone is smaller. The Chanac species differs from *Neohipparion montezumae* in its more nearly circular section of protocone and possibly in a tendency to relatively greater transverse diameter of the fossettes.

The characters of the Chanac species represented by specimen 21780 are in general like those of *Hipparion mohavense* of the Ricardo Pliocene, but they are shown in a form with smaller dimensions, and approaching the combination of characters of *N. gratum*. The species is evidently very near the Great Plains form of *N. gratum*, and it is not impossible that larger collections will exhibit a range of characters making even subspecific separation inadvisable.

An upper molar (figs. 8*a* to 8*c*) obtained by R. W. Pack of the United States Geological Survey on the north side of Hospital Creek (SE corner sec. 11, T 4 S, R 5 E) is similar to *N. g. tehonense* in dimensions. In this specimen the protocone is very small and approximately circular in cross-section.

An upper cheek-tooth figured in the earlier paper on the Tejon Hills fauna[5] may represent *N. g. tehonense*, or is possibly a more primitive form.

[5] Merriam, J. C., *op. cit.*, p. 286, fig. 1, 1915.

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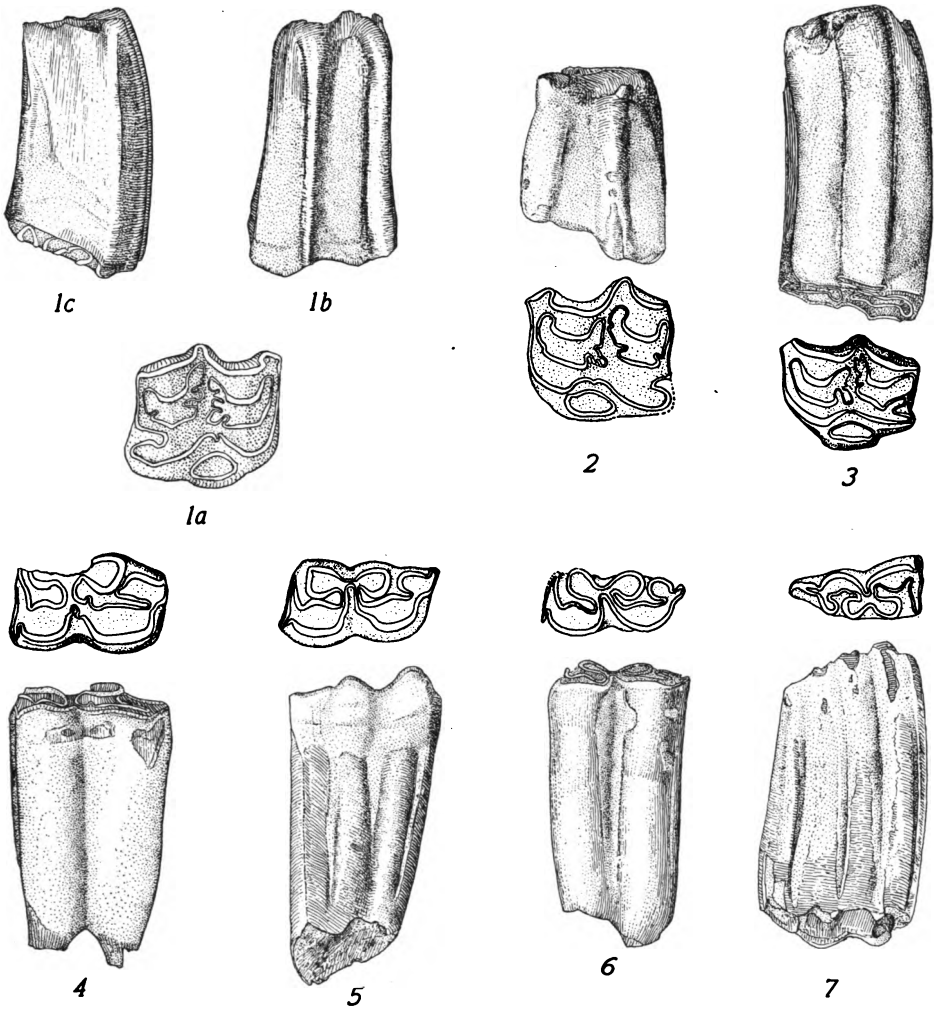

Fig. 1. *Neohipparion gratum tehonense* Merriam. M^{1}?, type specimen, no. 21780, natural size. Fig. 1*a*, occlusal view; fig. 1*b*, outer view; fig. 1*c*, posterior view. Chanac formation, southern end of San Joaquin Valley, California.

Fig. 2. *Neohipparion gratum tehonense* Merriam. P^{4}, no. 21782, natural size. Chanac formation, southern end of San Joaquin Valley, California.

Fig. 3. *Neohipparion*, near *molle* Merriam. M^{2}, no. 21781, natural size. Chanac formation, southern end of San Joaquin Valley, California.

Fig. 4. *Neohipparion gratum tehonense* Merriam. P_{4}, no. 21784, natural size. Chanac formation, southern end of San Joaquin Valley, California.

Fig. 5. *Neohipparion gratum tehonense* Merriam. M_{3}, no. 21785, natural size. Chanac formation, southern end of San Joaquin Valley, California.

Fig. 6. *Neohipparion*, near *gratum tehonense* Merriam. M_{3}?, no. 22364, natural size. Chanac formation, southern end of San Joaquin Valley, California.

Fig. 7. *Neohipparion*, near *gratum tehonense* Merriam. M_{3}, no. 21786, natural size. Chanac formation, southern end of San Joaquin Valley, California.

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A single fragmentary upper cheek-tooth (no. 1323) from beds presumed to belong to the Orinda Pliocene near Bolinger Canyon, California, shows the approximate form and dimensions of upper cheek-tooth of *N. g. tehonense* from the Tejon Hills. This specimen has been referred to as representing a Hipparion-like type distinct from two larger forms known from the Orinda.[6] It is possible that specimen 1323 represents a species in or near *N. g. tehonense.*

Several lower cheek-teeth from the Chanac formation of the Tejon Hills represent small *Hipparion* forms. It is possible that more than one species is present. If so the larger teeth as no. 21784 and 21785 (figs. 4 and 5) presumably represent *N. g. tehonense,* and the smaller specimens, as no. 22364 (fig. 6), might belong with the narrower upper cheek-teeth approaching *Neohipparion molle.* The small lower cheek-teeth from the Chanac formation approach the characters of a small Hipparion specimen (no. 22387) from the Ricardo beds above the uppermost basalt in the type section.

A lower cheek-tooth figured in the first discussion of the Tejon Hills fauna[7] corresponds to the smaller of these two faunas.

NEOHIPPARION, near MOLLE Merriam

A second upper molar, no. 21781 (fig. 3) from the Tejon Hills shows a much narrower crown, narrower fossettes and a flatter protocone than the specimen distinguished as *Neohipparion gratum tehonense.* In width of crown and narrowness of fossettes this specimen approaches *Neohipparion molle*[8] of the North Coalinga Jacalitos-Etchegoin section, but the protocone is narrower anteroposteriorly. In character of protocone no. 21781 is intermediate between *N. molle* and *N. g. tehonense.*

A M^3 (figs. 9*a* and 9*b*) evidently representing *Neohipparion molle,* obtained by R. W. Pack of the Geological Survey from beds overlying strata referred to the San Pablo, one mile north of Ingram Creek, on the east flank of the foothills of the Mount Diablo Range, shows the protocone a little narrower anteroposteriorly than in the type of *N. molle.* As the type of *N. molle* and the specimen found by Mr. Pack both represent M^3, it is possible that since the Tejon Hills specimen no. 21781 is a M^2 it may also belong in *N. molle,* as the protocone of M^2 is commonly shorter anteroposteriorly than in M^3.

[6] Merriam, J. C., Univ. Calif. Publ., Bull. Dept. Geol., vol. 7, p. 376, fig. 2, 1913.

[7] Merriam, J. C., Univ. Calif. Publ., Bull. Dept. Geol., vol. 8, p. 286.

[8] See Merriam, J. C., Univ. Calif. Publ., Bull. Dept. Geol., vol. 9, p. 3 and fig. 2, 1915.

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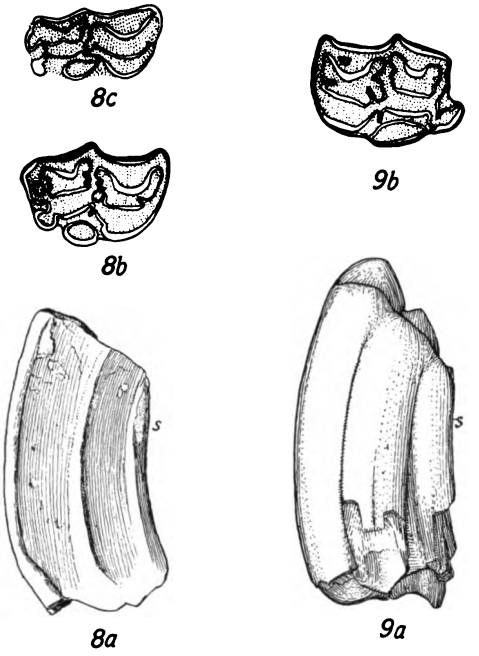
A M^3 (figs. 8*a* to 8*c*) obtained by Mr. Pack from beds overlying strata referred to San Pablo on the north side of Hospital Creek in the foothills of the Mount Diablo Range southwest of Modesto shows much the same width of crown and narrowness of fossettes as in M^3 obtained by Mr. Pack at Ingram Creek several miles to the southeast,



Figs. 8*a*, 8*b*, and 8*c*, *Neohipparion*, near *gratum tehonense* Merriam. M^3, natural size. Outer and occlusal views, and section at *s* near proximal end of distal third. Fig. 8*a* outer view; 8*b*, cross-section at *s*; fig. 8*c*, occlusal view of slightly worn tooth. Collected by R. W. Pack, of U. S. Geol. Survey, north side of Hospital Creek, western border of San Joaquin Valley, California, at S.E. corner sec. 11, T 4 S, R 5 E, M. D. B. & M.

Figs. 9*a* and 9*b*. *Neohipparion*, near *molle* Merriam. M^3, natural size. Fig. 9*a*, inner view; 9*b*, section at *s* near proximal end of distal third. Collected by R. W. Pack, of U. S. Geol. Survey, one mile north of Ingram Creek, western border of San Joaquin Valley, California.

but the protocone is small and almost circular in cross-section. If this specimen by any chance is shown to represent the same form as the M^3 from Ingram Creek there might be reason for considering the possible identity of *N. molle* and the *N. gratum* group. For the present there seems good reason for keeping the forms with wide protocone separate from the group with narrow protocone.

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MEASUREMENTS

	No. 21780
M^{1}?, anteroposterior diameter	19.1 mm.
M^{1}?, transverse diameter	17.7
M^{1}?, anteroposterior diameter of protocone	6.4
	No. 21781
M^{2}, anteroposterior diameter	17.8 mm.
M^{2}, transverse diameter at middle height of crown	*a*16.5
M^{2}, anteroposterior diameter of protocone	6.1
	No. 21782
P^{4}, anteroposterior diameter	18.8 mm.
P^{4}, transverse diameter	18.0
P^{4}, anteroposterior diameter of protocone	6.6
	No. 21784
P_{4}, anteroposterior diameter	20.3 mm.
P_{4}, transverse diameter	*a*11.1
P_{4}, anteroposterior diameter of metaconid-metastylid column	12.9
	No. 21785
M_{3}, anteroposterior diameter	19.3 mm.
M_{3}, transverse diameter	9.5
M_{3}, anteroposterior diameter of metaconid-metastylid column	11.3

a, approximate.

LIMB FRAGMENTS OF NEOHIPPARION

Two fragments of small metapodials represent an equid form not larger than the smallest species of *Merychippus* of the Barstow Miocene. Specimen 22365 (fig. 10), the proximal end of a small slender metacarpal three, possesses a narrow shaft suggesting that of the small Barstow *Merychippus*. The position of the unciform facet is, however, quite different from that in all of the many Barstow specimens examined by the writer. In the Barstow forms the unciform facet cuts that of the magnum at an angle ranging betwen 112 and 121.5 degrees. In the Ricardo horses, so far as known, the corresponding angle ranges between 128 and 131 degrees, and the unciform facet approaches distinctly nearer to the plane of the magnum facet than in the Barstow forms. In no. 22365 from the Tejon Hills the magnum-unciform angle is 131 degrees, as in the Ricardo horses.

A second metapodial specimen, no. 22376 (fig. 11) represents the distal end of a small metapodial of approximately the size shown in no. 22365. In this specimen the median keel is strongly developed on the posterior side but, as in the small Barstow *Merychippus*, it tends to fade out in the proximal region of the anterior side. In the Ricardo horses the keel is more strongly expressed.

In a fragmentary specimen representing a proximal phalanx, no. 22375 (fig. 13) the groove for reception of the distal keel of the meta-

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podial is well marked at the anterior side, showing that the metapodial keel was well expressed as in the *Hipparion* type. The phalanx represents an animal of somewhat larger size than the individuals from which the small metapodial specimens have been derived.

A small cuboid, no. 21787 (fig. 12), from locality 2751, has approximately the size of the corresponding element in small *Merychippus*

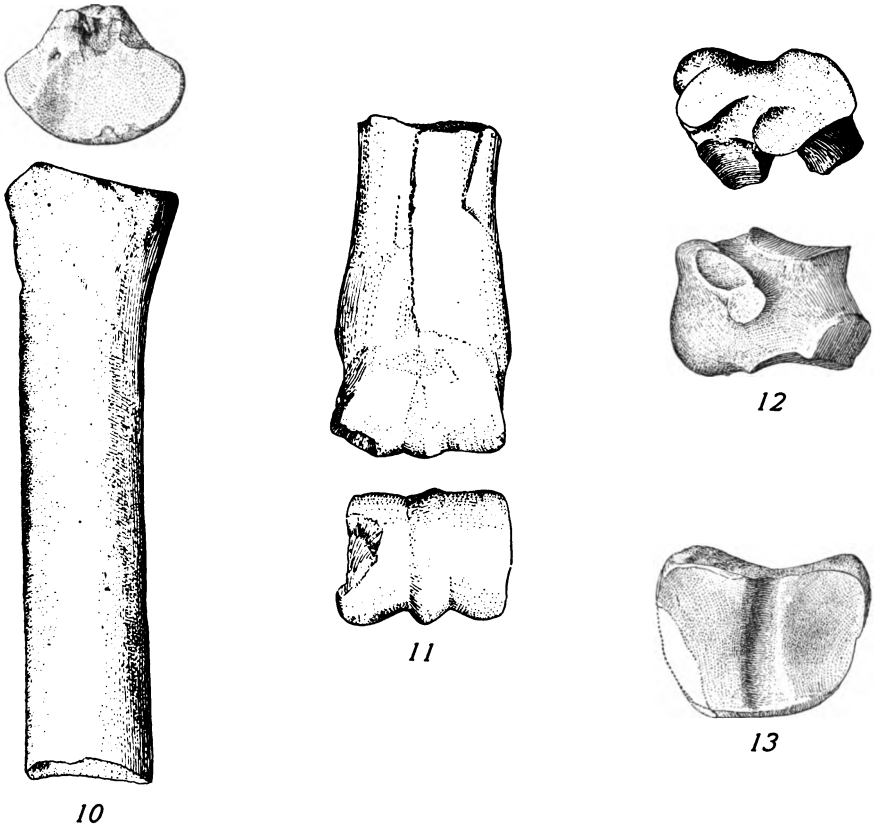

Fig. 10. *Neohipparion*, sp. Proximal end of metacarpal 3, natural size, anterior and proximal views, no. 22365. Chanac formation, southern end of San Joaquin Valley, California.

Fig. 11. *Neohipparion* or *Merychippus*. Distal end of metapodial, no. 22376, natural size. Chanac formation, southern end of San Joaquin Valley, California.

Fig. 12. *Neohipparion* or *Merychippus*. Cuboid, no. 21787, proximal and inner view, natural size. Chanac formation, southern end of San Joaquin Valley, California.

Fig. 13. *Neohipparion* or *Merychippus*. Proximal end of first phalanx, no. 22375, natural size. Chanac formation, southern end of San Joaquin Valley, California.

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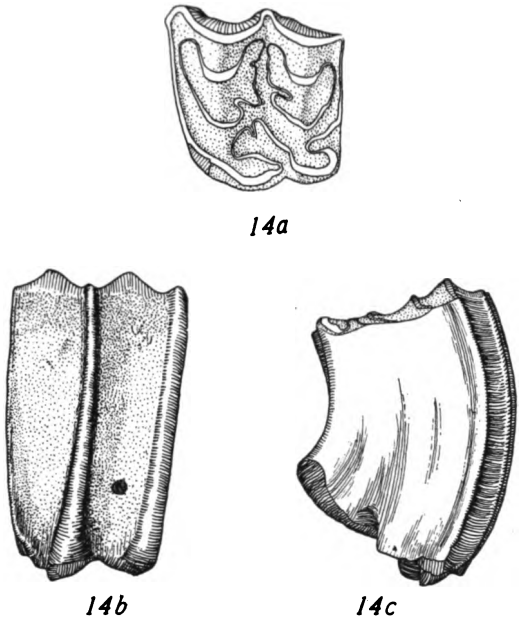
specimens from the Barstow Miocene. It differs from Barstow specimens in its slightly less prominent tuberosity, and in the situation of the posterior facet for the navicular somewhat nearer the proximal end of the element. In these particulars the Tejon Hills specimen approaches more closely the characters of an equid cuboid from the Ricardo Pliocene.

At locality 2751, in which the small equid metapodials, the phalanx, and the cuboid were found, no *Merychippus* teeth are known,



14a *14b* *14c*

Figs. 14*a* and 14*c*. *Protohippus tehonensis* Merriam. M^1?, type specimen, no. 21779, natural size. Fig. 14*a*, occlusal view; fig. 14*b*, outer view; fig. 14*c*, posterior view. Chanac formation, southern end of San Joaquin Valley, California.

but a number of *Neohipparion* teeth occurring there show dimensions not greater than those of the smallest *Merychippus* forms of the Barstow. It is therefore possible that the Merychippus-like limb elements represent the little *Neohipparion* species, in which resemblance to *Merychippus* is especially strong because small size has made unnecessary certain peculiar specializations in structure found in the larger and perhaps more nearly typical species of the genus.

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PROTOHIPPUS TEHONENSIS Merriam

P. tehonensis Merriam, Univ. Calif. Publ. Bull. Dept. Geol., vol. 9, p. 52, figs. 4*a* and 4*b* and 4*c*, 1915.

This species is represented by a single upper molar, no. 21779, the type specimen of the species (figs. 14*a* to 14*c*), found at locality 2751 in the Chanac formation of the Tejon Hills at the southern end of the Great Valley of California.

The West-American types to which *Protohippus tehonensis* shows closest resemblances are a form referred to *Pliohippus* or *Protohippus* from the lower portion of the Jacalitos-Etchegoin section of the North Coalinga[9] region, and a species near *Protohippus* represented by specimen 21423 from the Barstow Upper Miocene of the Mohave Desert. No teeth from the North Coalinga form have yet been obtained which correspond in position in the jaw to the type of *P. tehonensis*, so that a close comparison is not possible. The Barstow species is near the Tejon Hills form in many respects, but seems specifically distinct.

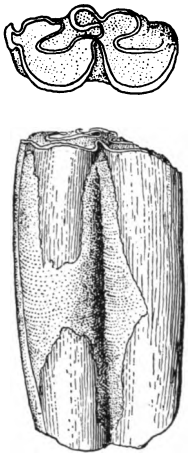

Fig. 15.—*Protohippus* or *Merychippus*. $P_{2}^{?}$, outer and occlusal views, no. 21484, natural size. Chanac formation, Comanche Creek, southern end of the San Joaquin Valley, California.

A lower cheek-tooth, no. 21484 (fig. 15) collected at Comanche Creek in the Tejon Hills by R. C. Stoner has a short metaconid-metastylid column with the valleys anterior and posterior to this column narrower than in Barstow Miocene species which have been considered as very advanced *Merychippus*. In the first discussion of the Tejon Hills fauna[10] the writer assumed that the species represented by this tooth might be more progressive than the most advanced Barstow form, and specifically distinct from it. This tooth may represent a *Protohippus* differing from the Barstow Miocene forms to much the same degree as the upper cheek-tooth in the type of *Protohippus tehonensis* differs from them. It is possible that the specimen represents *P. tehonensis*. The proof of this will require more and better material than that now available.

[9] See Merriam, J. C., Tertiary Vertebrate Faunas of the North Coalinga Region, Trans. Amer. Phil. Soc. N.S., vol. 22, part 3, p. 27, figs. 28*a* and 28*b*, 1915.

[10] Merriam, J. C., Univ. Calif. Publ., Bull. Dept. Geol., vol. 8, p. 287, 1915.

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PROSTHENNOPS, sp.

A number of fragments (no. 22459) from the Chanac formation represent a large peccary in which the cusps of the cheek-teeth are low or blunt-conical as in *Prosthennops*. This species approaches certain of the imperfectly known peccary forms from Pliocene faunas of the Pacific Coast and Great Basin regions. The material available

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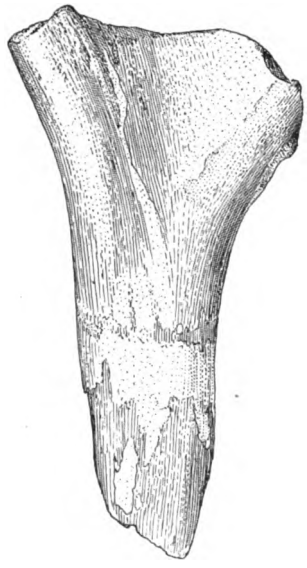

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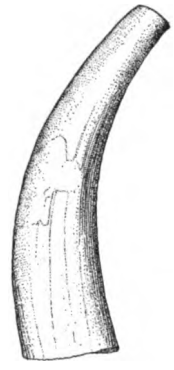

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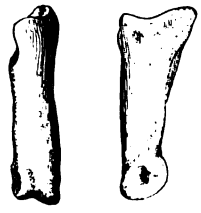

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Figs. 16 to 21. *Merycodus* near *necatus* Leidy. All figures natural size. Chanac formation, southern end of San Joaquin Valley, California. Specimens represented in figs. 19 and 20 collected by R. W. Pack of U. S. Geol. Survey.

Fig. 16. $M_{\bar{3}}$ or $M_{\bar{1}}$, occlusal and outer views, no. 22366; fig. 17, flattened superior portion of beam, no. 22332; fig. 18, terminal portion of horn, no. 22367; fig. 19, distal end of metatarsus, anterior side; fig. 20, proximal phalanx, lateral and superior views; fig. 21, second phalanx, lateral and superior views, no. 22460.

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from the Tejon Hills is too fragmentary, and the characters of the western Pliocene species are as yet too imperfectly known to permit a satisfactory comparison.

CAMELID, indet.

A fragment of the distal end of a large metapodial (no. 22377) from locality 2751 represents a camelid possibly of the *Pliauchenia* type. Other very fragmentary material also indicates the presence of large camels, but the material available is not sufficient to furnish the basis for even a generic determination.

MERYCODUS, near NECATUS Leidy

Fragmentary material obtained in the Tejon Hills region by R. W. Pack has already made possible definite determination of the presence of *Merycodus* in this region. Additional specimens secured by the 1915 party include a fragment of a lower jaw, a lower tooth, a number of fragmentary horn-cores, a scapula, and a second phalanx. One horn-core specimen (no. 22332, fig. 17) resembles the type of *Merycodus* found in the Ricardo and Barstow faunas of the Mohave Desert, and referred to *M. necatus*. Other portions of horn-cores, in which the cross-section is nearly circular, suggests *M. furcatus*. The second phalanx agrees approximately in size of corresponding parts with the first phalanx described in the earlier paper. The single lower tooth (no. 22366, fig. 16) is similar to $M_{\bar{2}}$ or $M_{\bar{1}}$ of a small species of *Merycodus* from the Ricardo. On the basis of the *Merycodus* material it is difficult to make a definite estimate of the age of the Chanac fauna, but the Tejon Hills form might well represent a stage near that of the Ricardo Pliocene.

Transmitted December 12, 1916.

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MAMMALIAN REMAINS FROM A LATE TERTIARY FORMATION AT IRONSIDE, OREGON

BY
JOHN C. MERRIAM

INTRODUCTION

In December, 1915, Dr. W. D. Matthew of the American Museum of Natural History kindly called the attention of the writer to a reported occurrence of fossil mammalian remains at a locality near Ironside, Malheur County, Oregon, the information having come to Dr. Matthew through Mr. H. E. Anthony, of the Department of Mammalogy and Ornithology in the American Museum. In subsequent correspondence Mr. Anthony informed the writer that a number of specimens had been obtained by his father, A. W. Anthony, at various localities in Malheur County, Oregon. In later correspondence, Mr. A. W. Anthony kindly furnished to the writer such information regarding the localities as was available. These discoveries suggested the occurrence of a fauna of importance in consideration of the history of mammals in the northern portion of the Great Basin province, and the writer accepted the invitation of Mr. Anthony to visit the Ironside region and examine the fossil-bearing formation.

In company with Dr. J. P. Buwalda of the University of California the writer had the opportunity to make a hurried survey of this region in June, 1916. The writer desires to express his appreciation of the courtesies extended by Mr. and Mrs. Anthony during the visit to Ironside, and for several interesting mammal specimens presented to the University by Mr. Anthony. It is also a pleasure to acknowledge the courtesy of Dr. Matthew and Mr. H. E. Anthony in furnishing the original information leading to investigations of this locality.

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OCCURRENCE AND AGE

The Ironside region, in which the mammalian finds are reported, is situated on the extreme northern border of Malheur County, Oregon, and is about thirty miles west of the middle of the eastern border of the state. This region lies at the southeastern base of the Blue Mountains, and is at the northern end of the great series of broken plains and short mountain ranges extending through southeastern Oregon into Nevada. The Ironside region is drained by Willow Creek, a tributary of Malheur River.

The beds in which the fossil remains were found by Mr. Anthony are in the immediate vicinity of Ironside Post Office. Some of the exposures are at an elevation of 3800 feet above sea-level. Somewhat to the east of Ironside similar sedimentary formations seem to be situated at an elevation of at least 4000 feet.

The mammal-bearing formation consists of buff sandy shales and shales with but little sand. The beds stand at varying angles ranging up to a degree of inclination of at least 20 degrees.

Locality 3037, at which the most important specimens were found, is located about three-fourths of a mile southwest of Ironside Post Office. At this locality, Mr. Anthony secured several fragments of upper teeth of *Hipparion,* a well-preserved lower tooth constituting the type of *Hipparion anthonyi,* a fragment of a rhinoceros tooth, and fragments of mastodontine teeth. One quarter of a mile south of locality 3037 Elmer Molthan obtained a well-preserved tooth of a mastodontine form apparently derived from beds not widely different in age from those at locality 3037.

The equid remains found in the sediments near Ironside represent a form most closely approaching in stage of evolution the *Hipparion* species from the Ricardo Pliocene. The stage of evolution of the fragmentary equid remains from Ironside is approximately that of the *Hipparion* species known from formations of the Great Basin and Pacific Coast provinces generally referred to the Pliocene. There is good reason for believing that the sediments at Ironside are not younger than middle Pliocene and not older than late Miocene. Future investigations should bring out more exactly the age relation of this formation to the Rattlesnake Pliocene of the John Day Valley. The fauna listed from the Idaho formation by Lindgren[1] in his important papers on the Tertiary formations of southwestern Idaho contains as one of its important elements equid forms which have been referred

[1] Lindgren, W., 20th Ann. Rep. U. S. Geol. Surv., Part 3, p. 99, 1900.

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to *Equus*, and there can be no doubt that the fauna at Ironside is not contemporaneous with that portion of the Idaho formation from which Lindgren's Idaho fauna was obtained.

At the present time some of the important problems in Tertiary geology and palaeontology of the Great Basin region depend upon an understanding of relationships between the John Day section and that of the Idaho region. By reason of its geographic situation the occurrence of mammal remains at Ironside may ultimately be of large service in the work of determining the time-relations between the Idaho sequence of faunas and the sequence of the John Day region. The Ironside locality is so situated that mapping of the region will make possible a determination of the stratigraphic relations of the sediments to the formations of the Snake River region of Idaho. Large exposures of sedimentary formations extend with few apparent interruptions from Ironside along Willow Creek and Malheur River to the type areas of the Idaho and Payette formations of the Snake River Valley. Some of these exposures presumably represent the Idaho formation, but it is not improbable that several formations or several stages of the later Tertiary are represented. The Ironside locality is also situated near the John Day Valley, in which there is represented the best stratigraphic section and the best palaeontologic sequence known as yet in the Great Basin province. It is probable that further palaeontologic and geologic studies will make it possible for us to understand the relation between the beds at Ironside and the John Day section. There is further the possibility that we may be able to determine the relation of the formation at Ironside to a great series of Tertiary deposits on the south side of the Blue Mountains, immediately to the south of the John Day Valley. The exposures on the south side of the Blue Mountains presumably represent a large part of the sequence of formations and faunas known within the John Day Valley.

HIPPARION ANTHONYI, n.sp.

Type specimen a second lower premolar, no. 22351, from Tertiary beds exposed three-fourths of a mile south of Ironside, Malheur County, Oregon.

The species is represented by a single tooth presented by A. W. Anthony of Ironside, Oregon. The horizon at which this specimen was found is presumed to be early Pliocene or latest Miocene.

Crown of medium height, narrow transversely. Enamel pattern showing uncommonly strong secondary plications. Several very strong secondary plications forming a sheaf of projecting folds on anterior side of hypoconid.

Specimen 22351 (figs. 1*a* to 1*c*) differs from *Merychippus* and *Pliohippus* in its greater relative size and stage of advance of the

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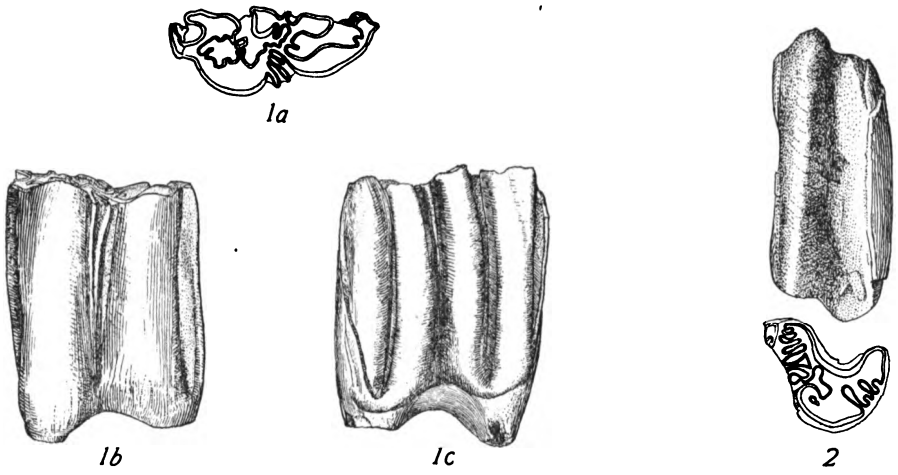
metaconid-metastylid column and entoconid, and in greater complication of its enamel folds. Of the Great Basin and Pacific Coast province equids *Hipparion mohavense callodonte* of the Ricardo Pliocene most nearly approaches the form from Ironside. In the West Coast *Merychippus* and *Pliohippus* species the metaconid-metastylid column is relatively shorter anteroposteriorly, and wider transversely, and the entoconid is not filled out to the same extent on the antero-internal angle. In general the entoconid of *Merychippus* and *Pliohippus* species is truncated obliquely on the antero-internal angle by a plane or curved face, extending outward and forward from the inner side, while in *Hipparion* this region is expanded and the cross-section of the entoconid tends to take on a rectangular outline, instead of the approximately triangular section seen in *Merychippus,* or the triangular to imperfectly rectangular but anteroposteriorly short section seen in *Pliohippus.*



Figs. 1*a* to 1*c*. *Hipparion anthonyi* Merriam. $P^{\frac{3}{4}}$, type specimen, no. 22351, natural size. Fig. 1*a*, occlusal view; fig. 1*b*, outer view; fig. 1*c*, inner view. From late Tertiary beds near Ironside, Oregon.

Fig. 2. *Hipparion anthonyi* Merriam?. Fragment of an upper cheek-tooth, no. 22355, natural size. From late Tertiary beds near Ironside, Oregon.

In no Great Basin or Pacific Coast species of *Merychippus, Protohippus,* or *Pliohippus* known to the writer does the enamel show such a high degree of secondary folding as in the specimen 22351 from Ironside. In *Hipparion mohavense callodonte* the enamel folds show much secondary crinkling, though less than in the Ironside form. The crown of *H. m. callodonte* is slightly larger and relatively thicker transversely, and the entoconid fuller on the antero-internal angle. In the

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type specimen of *H. m. callodonte* there are two small folds on the antero-external side of the hypoconid, but these folds are smaller than those in this position on the type of *H. anthonyi.* In other specimens from the Ricardo beds the structure differs more from that of no. 22351 than in the case of the type specimen of *H. m. callodonte.*

Of the *Hipparion* species from the northern end of the Great Basin, *Neohipparion leptode* of the Thousand Creek Pliocene shows a single very strong fold on the anterior side of the hypoconid, but the enamel is otherwise comparatively simple and the tooth crown in the type specimen, a second lower molar, is extremely narrow. No specimen of $P_{\bar{2}}$ of *N. leptode* is known. From the Rattlesnake Pliocene of the John Day region a specimen with a tooth crown of exactly the same height as the type specimen of *H. anthonyi* shows the enamel very much simpler and the crown relatively very much thicker transversely. $P_{\bar{2}}$ of *Hipparion condoni* from the Ellensburg formation is unknown. The enamel pattern in *H. condoni* is fairly complicated, but there is much less crinkling in long teeth than in the relatively short teeth of the type of *H. anthonyi.* There is a small fold on the anterior side of the hypoconid in a posterior premolar. The size of the crowns in *Hipparion condoni* suggests a type near the size of the Ironside specimen. Other characters indicate that the two forms are not specifically identical.

From such evidence as may be obtained from the single tooth available it may be concluded that no. 22351 from Ironside represents a species distinct from any thus far described in the Great Basin region and that the stage of evolution is not far from that of the Ricardo hipparions. This would indicate that the deposits near Ironside are of early Pliocene or late Miocene age.

A single fragment, no. 22355 (fig. 2), of an upper cheek-tooth from the deposits near Ironside consists of a cement-filled fossette with the enamel wall. The wall shows very strong plications, eight folds on one side and four on the other. This fragment evidently represents a *Hipparion* form similar in character to *H. anthonyi,* and it may be considered to represent that species. The form of fossette and degree of complication of the enamel folds bordering it suggest the character of the Rattlesnake Pliocene species with most complicated enamel.

Comparative Measurements	No. 22351 Ironside	H. m. callodonte No. 21311 Ricardo
$P_{\bar{2}}$, anteroposterior diameter	27.8 mm.	28.4
$P_{\bar{2}}$, transverse diameter across hypoconid	11.4	12.

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TETRABELODON?, sp.

A single lower cheek-tooth (no. 22883, fig. 3) found by Mr. Elmer Molthan one quarter of a mile south of locality 3037 near Ironside, Oregon, represents a large mastodontine form presumably from the same formation and from approximately the same horizon as the teeth

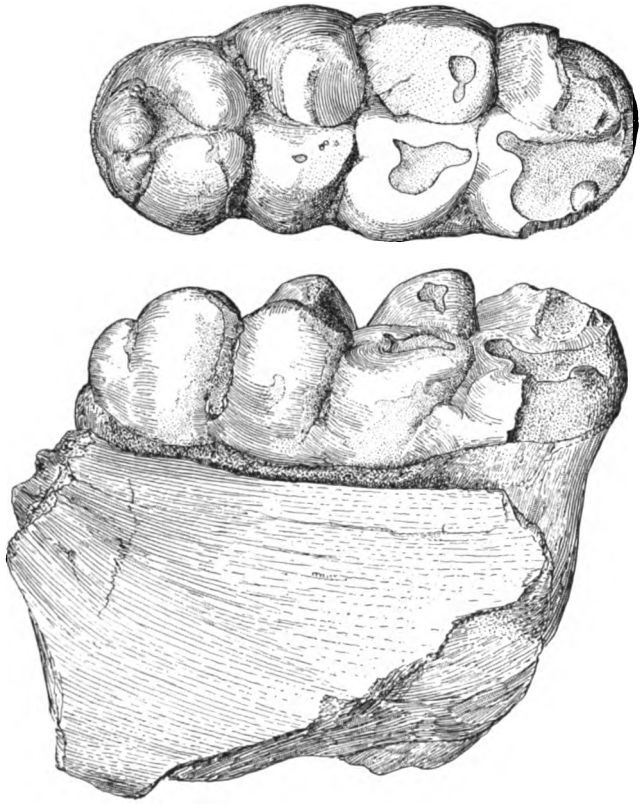

Fig. 3. *Tetrabelodon?*, sp. Lower cheek-tooth, no. 22883, natural size. Outer and occlusal views. From late Tertiary beds near Ironside, Oregon.

described as *Hipparion anthonyi*. The low conical tubercles are lightly connected transversely, and a few accessory tubercles are situated in the transverse valleys. This form resembles a type found in Great Basin beds referred to Pliocene or late Miocene, but the Pliocene mastodontine forms of this province are as yet very imperfectly known, and until further comparative studies have been made it is not possible to make satisfactory determination of the species repre-

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sented by this specimen. It is, however, of importance to place on record the occurrence of this form.

Two fragments of mastodontine teeth from locality 3037 represent a type which does not give evidence of differing from specimen 22883 found by Mr. Molthan.

MEASUREMENTS OF No. 22883

Greatest anteroposterior diameter	145 mm.
Greatest transverse diameter across second transverse crest from anterior end	62.

RHINOCEROTID, indet.

A fragment of an upper rhinoceros cheek-tooth from locality 3037 represents an indeterminate form. It is possible that future studies with the use of exceptionally good material for comparison may make possible an approximate determination of this tooth. For the present it is desirable to record the occurrence of rhinocerotid remains at this locality.

Transmitted December 18, 1916.

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Vol. 10, No. 10, pp. 137-164, 8 text-figures Issued February 5, 1917

RECENT STUDIES ON THE SKULL AND DENTITION OF NOTHROTHERIUM FROM RANCHO LA BREA

BY

CHESTER STOCK

UNIVERSITY OF CALIFORNIA PRESS

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RECENT STUDIES ON THE SKULL AND DENTITION OF NOTHROTHERIUM FROM RANCHO LA BREA

BY

CHESTER STOCK

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INTRODUCTION

The first remains of the Pleistocene ground-sloth *Nothrotherium* (*Coelodon*) were found in a Brazilian cavern by P. W. Lund,[1] who believed the fossils to represent a small *Megatherium*. Lund later recognized the distinctness of the form and established the genus *Coelodon*.[2] Material belonging to a young individual subsequently collected by Lund was fully described and compared with other

[1] Lund, P. W., Om Huler i Kalksteen i det Indre af Brasilien, der Tildeels Indeholde Fossile Knokler, Pt. 1, Kgl. Danske Vidensk. Selskabs Skr., 4 Raekke, naturvidenskabelige og mathematiske Afhandl., 6 deel, pp. 207–248, 2 pls., 1837.

[2] Lydekker in 1889 replaced *Coelodon* Lund by *Nothrotherium*, stating that the former name was preoccupied. Recently Winge (E Museo Lundii, vol. 3, pt. 2, pp. 136–138, 287–288, pls. 24–25, 1915) has returned to Lund's original designation of the genus.

The name *Coelodon* was first used by Audinet-Serville (Ann. Soc. Entom. France, 1832, p. 164) for a genus of long-horned, wood-boring beetles (Fam. Cerambycidae) from Senegal. Since Lund did not propose *Coelodon* for the ground-sloth from the Brazilian cavern until 1839, there is no question as to priority.

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Pleistocene genera by Reinhardt[3] in 1878. The relationship of this genus to the Miocene ground-sloths of Patagonia has been discussed by Scott[4] and Ameghino.[5]

It is of considerable interest to note that *Nothrotherium* has only recently been definitely recognized, although tentatively recorded by Sinclair[6] in 1905, as a member of the North American Pleistocene fauna. Its distribution over the northern continent, as indicated by the known occurrences in Pleistocene deposits of California and Texas,[7] is apparently much more restricted than that of *Megalonyx* and *Mylodon*. It seems not improbable that the genus, when known more completely, will be recognized in other Pleistocene faunas. Among the Rancho La Brea edentates, the nothrotheres rank next to the mylodont sloths in abundance, but are present in far smaller numbers than the latter. Curiously enough, *Nothrotherium* is represented in the asphalt by a greater number of individuals than *Megalonyx*.

The Museum of History, Science and Art of Los Angeles contains in its Rancho La Brea collection eight more or less complete crania with fragments of perhaps four other individuals. A number of mandibles are also available. All of the better preserved skulls are much larger than Reinhardt's specimen and belong to adult or nearly adult individuals. Associated with the skulls is one nearly complete skeleton and many separate parts of skeletons. In the present preliminary discussion only the skull of the nothrotheres is considered. It is planned to give a fuller account of *Nothrotherium* from the asphalt beds in which all the material of the genus will be reviewed.

The present report is based entirely on material contained in the

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[3] Reinhardt, J., Kaempedovendyr-Slaegten Coelodon, Vidensk. Selsk. Skr., 5 Raekke, naturvidenskabelig og mathematisk Afhandl., vol. 12, 3, pp. 253–349, 5 pls., Copenhagen, 1878.

[4] Scott, W. B., Rept. Prin. Univ. Exp. Patag., 1896–1899, vol. 5, Gravigrada, 1903–1904.

[5] Ameghino, F., Notas sobre una pequeña coleccion de huesos de mamiferos procedentes de las grutas calcáreas de Iporanga en el Estado de São Paulo-Brazil, Revista do Museu Paulista, vol. 7, pp. 74–119, 1907.

[6] Sinclair, W. J., New mammalia from the quaternary caves of California, Univ. Calif. Publ. Bull. Dept. Geol., vol. 4, pp. 153–155, pl. 23, figs. 1–5*a* and 8, 1905.

[7] In a discussion of the quicksilver deposits of the Terlingua district, Brewster County, Texas, H. W. Turner makes mention (Economic Geology, vol. 1, p. 275, 1906) of the finding of ground-sloth remains in a fissure deposit. This material was submitted to Professor J. C. Merriam, who identified several teeth as belonging to *Nothrotherium*. The specimens were placed in the Museum of the California Academy of Sciences in San Francisco, where they were destroyed by the fire of April 18, 1906.

Recently O. P. Hay has described (Proc. U. S. Nat. Mus., vol. 51, pp. 116–123, pls. 6 and 7, 1916) a new species, *Nothrotherium texanum*, from the Pleistocene of Texas.

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Museum of History, Science and Art of Los Angeles. For the privilege of studying this remarkable collection of nothrotheres, I am very greatly indebted to Director Frank S. Daggett. Thanks are due also to the other members of the Museum staff for many courtesies extended. I am obligated to Professor John C. Merriam for assistance and much friendly advice and criticism during the progress of the research on the Rancho La Brea edentates.

The drawings reproduced in this paper have been prepared by Mrs. Louise Nash.

CRANIUM

The largest available skull of *Nothrotherium* from Rancho La Brea is approximately as long as a skull of *Megalonyx jeffersoni* described

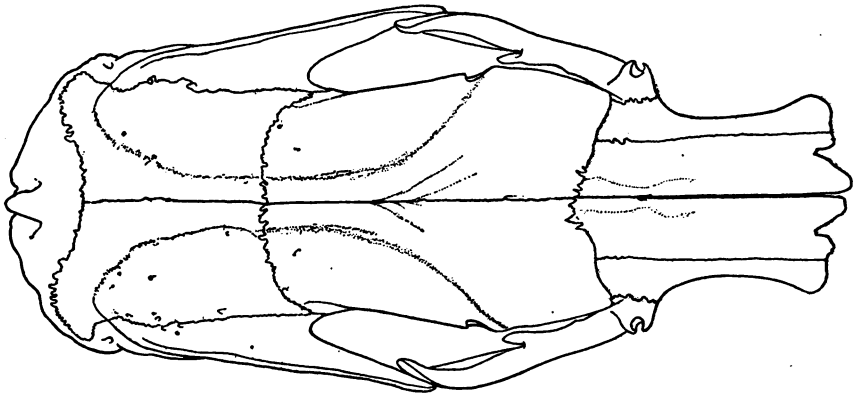

Fig. 1. *Nothrotherium shastense* Sinclair. Cranium, no. 208 M. H. S. A., superior view, × ⅛. Rancho La Brea Beds, California.

by Leidy.[8] With this exception the specimens from the asphalt beds are all somewhat shorter than either *M. jeffersoni* or *M. leidyi*. In marked contrast to *Megalonyx*, however, is the relative slenderness of skull in *Nothrotherium*. In this respect the latter genus more closely resembles the Miocene Megalonychidae and Planopsidae,[9] from which it has also deviated less than *Megalonyx* in general shape of skull. Contrasted with *Planops*, one of the largest of the Santa Cruz Gravigrada, the skull of the Pleistocene genus is distinctly larger.

[8] Leidy, J., A memoir on the extinct sloth tribe of North America, Smithson. Contrib. Knowl., vol. 7, 1855; see measurements of the Dickeson specimen, p. 13.

[9] Scott, W. B., Rept. Prin. Univ. Exp. Patag., 1896–1899, vol. 5, p. 164, fig. 16, 1903.

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Nothrotherium differs from *Megalonyx* and agrees with *Hapalops* in the long and slender muzzle (fig. 1). In no. 632[10] the anterior ends of the maxillaries are noticeably flared. This character is less apparent in no. 633 and may be but little developed as in no. 634. The nasals are long and may be more decidedly arched in some skulls than in others. In no. 632 the fronto-nasal suture is convex posteriorly, thus resembling most species of *Hapalops*. This suture may, however, vary in *Nothrotherium*. It may be decidedly V-shaped as in no. 633, but in this specimen the original suture appears to have been somewhat in advance of the present separation. In no. 633 the nasals have apparently fused with the frontals, a secondary or pseudo fronto-nasal suture developing posterior to the original suture. A similar abnormality in the separation between nasal and frontal has been noted in skulls of *Mylodon harlani* from Rancho La Brea.[11]

In some specimens the lachrymal is not as prominent in superior view as in species of *Hapalops*, but its canal is very much in evidence. In *Megalonyx* the lachrymal and its canal are apparently not to be seen in dorsal aspect. The postorbital processes of the frontals may be very blunt in some specimens of *Nothrotherium*, thus being more as in *Megalonyx* and differing from *Megatherium*. Between and slightly posterior to the supraorbital borders, the frontals sag in the middle line. This sag is perhaps most evident in the largest specimen, no. 634, and in skull 203. In skull 15 it is practically absent.

The temporal ridges are but faintly marked in all specimens from Rancho La Brea, *Nothrotherium* thus resembling the Miocene Megalonychidae. At the coronal suture where the crests approach each other most closely, the distance between them may vary. There is never a pronounced sagittal or lambdoidal crest present as in *Megalonyx*. In front of the weak lambdoidal crest the dorso-lateral surface of the parietal may sag slightly. This sag is distinctly developed in no. 633 where it reaches the median dorsal suture of the cranium, or it is hardly discernible, as in skulls 632 and 634. In all skulls of *Nothrotherium* the supraoccipital is more prominent in superior view than in *Megalonyx*. It is very evident in skull 208 (fig. 1).

As indicated in a former paper,[12] the Brazilian species described

[10] All numbers used in the following comparisons in this paper, unless otherwise stated, are the catalogue numbers of specimens in the Museum of History, Science and Art of Los Angeles.

[11] Stock, C., Skull and dentition of the Mylodont sloths of Rancho La Brea, Univ. Calif. Publ. Bull. Dept. Geol., vol. 8, p. 322, 1914.

[12] Stock C., Univ. Calif. Publ. Bull. Dept. Geol., vol. 7, p. 343, 1913.

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by Reinhardt[13] differs noticeably from the Californian form in dorsal contour of skull (fig. 2). It is possible that this difference is in part due to age, but it is probably a specific distinction. In *Hapalops longiceps* the frontal is more elevated than the parietal, while in *H. vulpiceps* and *H. gracilidens* the reverse is true, the parietal being much more highly vaulted than the frontal. In the elevation of the frontal the Rancho La Brea species of *Nothrotherium* approaches *Planops* most closely. *Megalonyx* differs from its Pleistocene contemporary in the straight dorsal contour of the skull.

The zygomatic process of the squamosal is long and slender. It is relatively longer than in *H. longiceps*. In skull 15, used as the type in the first description[14] of the species from Rancho La Brea, this

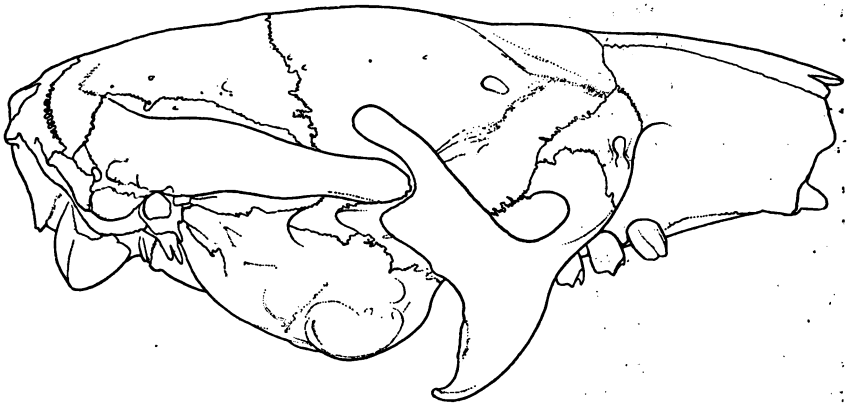

Fig. 2. *Nothrotherium shastense* Sinclair. Cranium, no. 208 M. H. S. A., lateral view, × ⅓. Rancho La Brea Beds, California.

process is broken. The malars have been preserved in several skulls, notably in no. 208, where they are firmly attached at the base to lachrymal and maxillary. The malar resembles *Hapalops* in slenderness, and, as in that genus, is not fused with the zygomatic process of the squamosal. It differs from *H. longiceps* in (1) its relatively shorter anteroposterior extent, (2) an absence of a marked outward flare of the infraorbital border, (3) a shorter dorsal prong, but deeper notch for the zygomatic process of the squamosal, and (4) a relatively longer and more slender ventral prong.

[13] Reinhardt, J., Kaempedovendyr-Slaegten Coelodon, Vidensk. Selsk. Skr., 5 Raekke, naturvidenskabelig og mathematisk Afhandl., vol. 12, 3, pp. 253–349, 5 pls., Copenhagen, 1878.

[14] Stock, C., *op. cit.*, pp. 342–350, 1913.

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In *Megalonyx* the zygomatic process of the squamosal is much heavier than in *Nothrotherium*. In *M. leidyi*[15] and in *Megatherium americanum*[16] this process has completely fused with the malar. The postorbital border of the malar is decidedly more curved in *M. leidyi* than in *Nothrotherium*. The ventral prong is also relatively more slender at the base in *M. leidyi*.

The parietal sends downward and forward a narrow extension which usually meets the lateral portion of the alisphenoid. Occasionally this extension does not reach the alisphenoid but is interrupted by the frontal. The foramen rotundum and foramen ovale open together as in *Hapalops* and may form a slightly larger orifice than the foramen lacerum anterius. The orbitosphenoid is not clearly defined by suture. The optic foramen lies at the posterior end of a groove which widens anteriorly, and may be somewhat obscured by the overhanging of the frontal.

The premaxillaries, although originally present in the Rancho La Brea skulls, have not been thus far recognized in the collections. Their articulating surfaces on the maxillaries reveal some interesting peculiarities. On each side of the small median V-shaped notch the maxillary is thickened, especially the palatal portion. This thickening of the maxillary extends well up along the sides of the external narial opening, in some skulls reaching nearly halfway to the top of the orifice. In the Brazilian species described by Reinhardt, the premaxillary is shown as a Y-shaped element. In Reinhardt's figure[17] the median arm of the posterior end is seen to be short, while the lateral arm is longer and appears to curve upward. This apparently corresponds with the thickening of the maxillary at the inferior external angle of the narial opening. The anterior arm of the premaxillary was presumably not very long in the *Nothrotherium* from the asphalt beds.

In *Hapalops* a similar Y-shaped premaxillary is present. The articulation of this element with the maxillary may somewhat resemble that in the Rancho La Brea genus. The articulation between premaxillary and the end of the palatal portion of the maxillary is not as extensive in *Nothrotherium* as in *Hyperleptus*. In the Miocene

[15] Lindahl, J., Description of a skull of Megalonyx leidyi, n.sp., Trans. Amer. Philos. Soc., vol. 17, n.s., pp. 4–6, pl. 1, 1893.

[16] Owen, R., On the Megatherium (Megatherium americanum, Cuvier and Blumenbach), Pt. 3, The skull, Philos. Trans. Roy. Soc. Lond., vol. 146, pl. 21, fig. 1, 1856.

[17] Reinhardt, J., *op. cit.*, pl. 1, fig. 3, 1878.

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Planops, according to Scott, "the premaxillae were evidently large, the facets for them upon the maxillaries being of uncommon size, while the median notch for the spines is a characteristically deep and narrow V."[18] In *Megalonyx jeffersoni* Leidy describes[19] the premaxillaries as "simple, oblong, quadrilateral plates, a little more than two inches in depth, and three quarters of an inch in breadth."

Owing to the slenderness of the muzzle, the anterior aspect of the skull of *Nothrotherium* is decidedly unlike that in *Megalonyx.* In *M. jeffersoni,* according to Leidy, "The end of the face is relatively narrower and higher than in *Mylodon;* and in outline is more vertically oblong quadrilateral, with the upper margin convex and the sides nearly vertical."[20] In *Nothrotherium* where the first or canini-

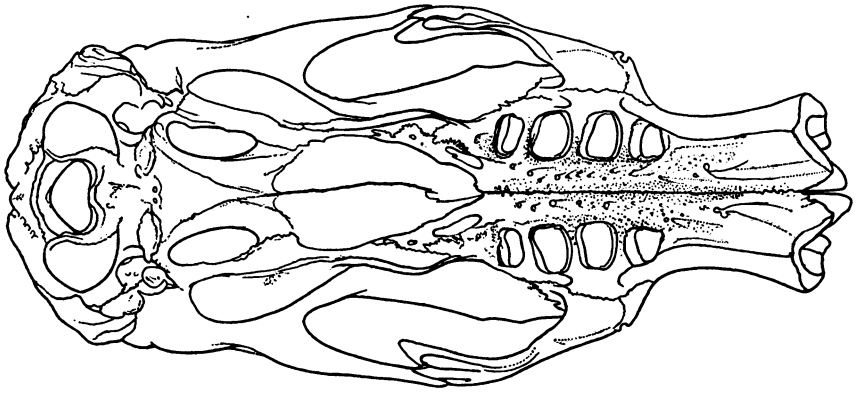

Fig. 3. *Nothrotherium shastense* Sinclair. Cranium, no. 208 M. H. S. A., inferior view, × ⅓. Rancho La Brea Beds, California.

form tooth is absent, the anterior end of the skull is nearly round or oval. The external narial opening is relatively wide transversely as contrasted with the height. The lateral walls show no indication of notching as in *Megatherium.* With the disappearance of the caniniform tooth in *Nothrotherium* the depression of the lateral wall of the maxillary anterior to M^2 becomes nearly obsolete. This depression is better developed in *Hapalops* and is very pronounced in *Megalonyx.*

The palate (fig. 3) anterior to M^2 may be approximately twice as wide as between the tooth-rows. The lateral borders of the edentulous portion of the palate may be nearly straight as in no. 632 or

[18] Scott, W. B., Rept. Prin. Univ. Exp. Patag., 1896–1899, vol. 5, p. 322, 1904.
[19] Leidy, J., *op. cit.,* p. 11, 1855.
[20] Leidy, J., *ibid.*

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they may become convex outward as in skull 634. In the outwardly convex borders of the palate no. 634 resembles greatly species of *Hapalops* in which the first or caniniform tooth is some distance posterior to the end of the skull. In particular does it resemble a skull of *Planops longirostris* illustrated by Scott.[21] In *Megalonyx* the palate in front of M^2 is relatively shorter and the sides diverge anteriorly more than in *Nothrotherium*.

The palate is flat or somewhat convex. It is considerably pitted with large and small foramina, resembling *Hapalops* in this respect more than *Planops*. On either side of the raised median suture and between the tooth-rows extends a series of large foramina. From the most anterior of these, which occupy a position approximately at the middle of the predental portion of the palate, widening grooves extend forward to nearly the front end of the skull. Scott describes the edentulous space in *H. longiceps* as having "a well-defined groove on each external side, with raised outer border."[22] In no. 634 the anterior openings of the palatine canals lie between the points of greatest outward curvature of the margins of the palate. In skull 166 they open on the surface of the palate much more posteriorly, or nearer M^2, than in the remaining skulls.

The palatine suture, which for some distance parallels the margin of the postpalatine notch, meets the middle line of the palate between or behind the posterior ends of M^4. The postero-internal border of the alveolus for M^5 may be somewhat elevated, causing the palate to become transversely concave in this region. The posterior opening of the palatine canal opens at the anterior end of an elongate pit. The latter is situated on the palatine shelf bordering the postpalatine notch, and its anterior border is usually posterior to the last superior tooth. The pit may, however, extend well along the inner side of M^5. At the posterior end of the elongate pit a second opening leads to the lateral cranial wall. The large foramina, extending in a row on either side of the median suture of the palate, open directly into the palatine canals.

The postpalatine notch is always more acute than in the skull described by Reinhardt, and apparently reached slightly farther forward in the Rancho La Brea species. Its position is, however, well posterior to M^5. In *Planops magnus* Scott states that "The posterior nares do not extend so far forward as in most of the contemporary

[21] Scott, W. B., *op. cit.*, pl. 59, fig. 1*a*, 1904.
[22] Scott, W. B., *op cit.*, p. 185, 1903.

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Gravigrada, the front margin being a little behind [5] . . ."[23] The pterygoid plates continue backward from the shelf, formed by palatine and in part also by maxillary, along either side of the postpalatine notch. On these plates the inferior border is broadly rounded while in *Megatherium* it is angulate. In the Rancho La Brea *Nothrotherium* the plates are very similar to those in Reinhardt's specimen, and posteriorly are seen to enlarge into great bullae as in the latter form. These bullae differ decidedly from those shown by Reinhardt in being pierced along their inner ventral wall by a large and elongate orifice. Between the outer border of this opening and the inferior border of the pterygoid plate a broad groove extends from the outer posterior to the inner anterior side, diagonally across the inflated portion. The posterior border of the pterygoid may approach the occipital condyles very closely, thus differing decidedly from *Megalonyx*.

The inflated pterygoids are perfectly preserved in skull 208 (fig. 3) in which specimen they swell outward somewhat below the base of the zygoma and behind the glenoid fossa. They are much better preserved than in the skull, no. 15, originally described. In an earlier note on the skull of the Rancho La Brea *Nothrotherium* the writer inadvertently referred to these structures as tympanic bullae, stating that Reinhardt considered them as such in the Brazilian species. In this respect unfortunately Reinhardt has been misquoted, as he distinctly and correctly interprets them as being merely inflations of the posterior portions of the pterygoid. The pterygoid bullae in all the skulls except one are large. In no. 313, which is the smallest of the eight nearly complete skulls contained in the Museum of History, Science and Art of Los Angeles, and evidently belongs to a somewhat younger individual, the posterior inflation of the pterygoid is exceedingly small and is restricted to the extreme posterior end of the pterygoid. The ventral opening of the bulla is also small. Between the cavity and the descending plate, the pterygoid is thickened in this specimen.

In *Hapalops longiceps*, according to Scott, "The pterygoids are narrow, inconspicuous plates, closely applied to the descending processes of the alisphenoids, and not in the least like the swollen, bulla-like bones of *Nothrotherium*, which Reinhardt has described ('78, 336)."[24] Structures comparable to the pterygoid bullae of *Nothrotherium* and occupying a similar position are absent in *Megalonyx*. Lindahl, however, records that in *M. leidyi*, "capacious air sinuses

[23] Scott, W. B., *op. cit.*, p. 326, 1904.

[24] Scott, W. B., *op. cit.*, p. 185, 1903.

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extend backward in the root of the pterygoid (Pl. III), and branch off from there forward into the alveolar wall of the maxilla.''[25] An extensive inflation of the pterygoid in skulls of the tree sloths *Choloepus* and *Hemibradypus* has been noted by Anthony.[26] With reference to the air sinuses in the skull of the former genus, he states:

> Le sinus sphénoïdal s'étend latéralement à l'intérieur des ptérygoïdes, se prolonge dans le temporal, envahissant la base de l'apophyse zygomatique et venant presque au contact des prolongements latéraux du sinus frontal. Le crâne osseux présente un orifice situé à la face interne et antérieure de chaque ptérygoïde et qui conduit dans ce sinus.[27]

Nothrotherium therefore resembles *Choloepus* very closely not only in the large size of the pterygoid inflation but also in the presence of an orifice perforating the inner wall of the pterygoid.

The alisphenoid forms not only the roof of the pterygoid bulla but the dorso-internal wall as well. In some skulls an internal continuation of the vacuity of the pterygoid extends toward the middle line. In skull 634 this extension, lying below the ventral surface of the basisphenoid, is separated from its fellow of the opposite side by a median partition only 2 mm. in thickness. The development of these internal sinuses varies from the extreme case seen in no. 634 to their entire absence as in skull 15.

The basisphenoid is concave transversely and tapers towards the anterior end where the pterygoid bullae approach each other most closely.

The basioccipital in most skulls is short, relatively much more so than in *Megalonyx*. The tympanic, as seen in no. 208, resembles *Hapalops* in the incomplete, irregular circle of bone which encloses ventrally the large external auditory meatus. Anteriorly the tympanic may touch the dilated wall of the pterygoid. Posterior to the tympanic is the stylo-hyal process with its ovoid depression. It is situated much closer to the occipital condyle than in *Megalonyx*. The small condylar foramen lies in a pit and may be entirely hidden by the border of the occipital condyle. In *Hapalops* and especially in *Megalonyx* this foramen is well in front of the occipital condyle.

The paroccipital process, as in *Hapalops*, is inconspicuous, being much less prominent than in *Megalonyx*. Between it and the stylo-

[25] Lindahl, J., Description of a skull of Megalonyx leidyi, n.sp., Trans. Amer. Philos. Soc., vol. 17, n.s., p. 7, 1893.

[26] Anthony, R., Recherches anatomiques sur les bradypes arboricoles, etc., Ann. Sci. Nat., ser. 9 (Zool.), vol. 9, pp. 157–285, pls. 2–6, 1909.

[27] Anthony, R., *ibid.*, p. 178, 1909.

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hyal process is a deep groove which reaches the occiput and extends for a short way along its lateral border. The position of the occipital condyles with reference to the pterygoid bullae has already been noted. The condyles in ventral aspect are not obliquely placed as in *Megalonyx,* and project posteriorly much less than in that genus or in *Megatherium.* They may be widely separated as in no. 313, or much closer together as in no. 203. By far the greater articulating surface of the condyles is directed downward, forward and outward. Leidy states that in *Megalonyx* the articulating surface of the condyles is bent at about the middle. In no. 633 the dorsal portion of the outer border of the condyle is curiously flattened by a rough and rather extensive surface. The foramen magnum may be transversely oval in shape. It opens more downward than in *Megalonyx.*

The base of the zygoma is long, and the glenoid fossa is somewhat concave transversely. The zygomatic process is quite like that in

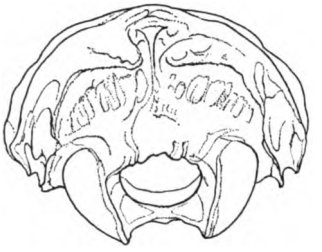

Fig. 4. *Nothrotherium shastense* Sinclair. Cranium, no. 208 M. H. S. A., posterior view, × ⅓. Rancho La Brea Beds, California.

Hapalops, differing from *Megalonyx* in not projecting so far from the side of the skull.

As in Miocene genera, the occiput of the Rancho La Brea *Nothrotherium* is nearly vertical or inclined slightly beyond the occipital condyles. The supraoccipital forms usually an extensive, forwardly inclined surface. In posterior view (fig. 4) the condyles are seen to be as a rule more widely separated than in *Hapalops.* In no. 203 their position is more as in the latter genus. The posterior face of the condyles is relatively smaller than in *Hapalops.* The dorsal lip of the foramen magnum is notched at the middle only in skulls 15 and 166. The median vertical ridge of the occiput does not usually reach the foramen magnum. It is sharp below but greatly broadens dorsally on the surface of the supraoccipital. Where the vertical surface of the occiput meets the forwardly inclined surface a heavy, rugose, trans-

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verse ridge is formed as in *Megalonyx*. This ridge swings outward and downward and in some skulls is directly connected with the posterior surface of the stylohyal process. The crest of the occiput is not prominent except along its lower end.

MEASUREMENTS OF CRANIUM	N. shastense No. 166 M. H. S. A. Rancho La Brea	N. shastense No. 208 M. H. S. A. Rancho La Brea	N. shastense No. 313 M. H. S. A. Rancho La Brea	N. shastense No. 632 M. H. S. A. Rancho La Brea	N. shastense No. 633 M. H. S. A. Rancho La Brea	N. shastense No. 634 M. H. S. A. Rancho La Brea
Length from anterior end of maxillaries to posterior end of occipital condyles	320 mm.	309	302	313.6	.....	330
Length from anterior end of nasals to posterior end of supraoccipital	339.8	336.3	320.4	333.3	339.5	352
Length of palate, from anterior end of maxillaries to postpalatine notch	141.7	*a*135.4	127	131	.....	144
Greatest width of palate anterior to M^1	45.8	46.2	42.9	42.9	.....	48
Width of palate between alveoli of M^2	22	23.6	21.4	20.6	24	21.8
Greatest width of pterygoid bulla	41.4	43.2	17.4	*a*37.9	37.4	*a*41.6
Greatest length of internal orifice of pterygoid bulla	37.6	38.2	21.7	36.7	30.5	.....
Greatest width of internal orifice of pterygoid bulla	.....	14.4	*a*8.5	.....	12	.....
Least distance between pterygoid bullae	.....	.....	.....	23.3	21.3	21.8
Mastoid width above stylohyal processes	112.8	118.4	110.5	114	114	120.6
Greatest width across occipital condyles	75.4	78	78.4	74.9	78.4	81.1
Transverse diameter of foramen magnum, internal measurement	33.5	29.6	30	32	31.8	36
Dorso-ventral diameter of foramen magnum, internal measurement	28.7	24.9	26.3	24.2	24.2	29.5
Height of occiput from plane of basioccipital to lambdoidal suture	79.6	87.7	80.7	78.5	76.5	85
Greatest width of muzzle at anterior end	70	78.2	65.5	73.9	73.4	73.4
Length of nasals	114.5	114.7	130.8	111.9	134.3	122.4
Greatest width above orbits	103.2	104.9	98.3	104.3	102.9	112.9
Least width behind orbits, in region of coronal suture	78.2	80	82	78.5	77	83.8
Width, measured across anterior ends of zygomatic processes of squamosals	153.8	153.5	.....	.....	.....	-----
Least distance between outer sides of pterygoid plates	61	56.4	.....	.....	.....	-----
Greatest height from ventral border of pterygoid plate to highest elevation of frontals	134.7	139.9	*a*130.3	.....	.....	-----

a, approximate.

MANDIBLE

The most striking characteristic of the lower jaw of *Nothrotherium* is its great similarity to that of *Hapalops*. The former genus in this regard is decidedly closer to the Miocene form than to its Pleistocene

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contemporary, *Megalonyx*. In general structure of mandible *Nothrotherium* bears the same relation to *Hapalops* as *Megalonyx* does to *Eucholoeops*. The lower jaw of an apparently adult individual, no. 208, of the Rancho La Brea species is approximately twice as large as that in *Hapalops longiceps*. Although the mandible may very closely approach *Megalonyx* in total length, yet it differs from that genus in its very decided slenderness.

In both *Hapalops* and *Nothrotherium* the predentary portion of the jaw is produced anteriorly into a long beak which in the latter genus is also deeply concave. The edentulous beak or spout (fig. 5) is much more elongate than in *Megalonyx*. The anterior end may be rather acutely tapering as in no. 208 or rounding as in no. 456.

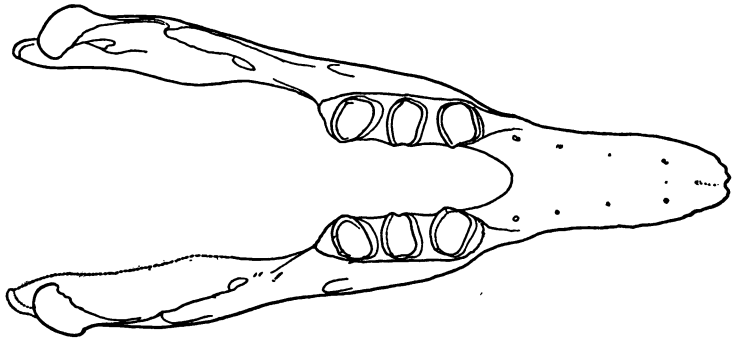

Fig. 5. *Nothrotherium shastense* Sinclair. Mandible, no. 166 M. H. S. A., superior view, × ⅓. Rancho La Brea Beds, California.

As pointed out by Scott, the lower border of the ramus in *Nothrotherium* is less sinuous than in *Hapalops*. In the former genus it forms an even convexity which reaches its maximum development below the third inferior tooth. This border is more strongly convex than in *Megalonyx,* but decidedly less so than in *Megatherium*. The inferior border posterior to the tooth series and reaching to the end of the angular process is less decidedly concave in *Nothrotherium* than in *Hapalops*.

The symphyseal keel is long and sharp, but not as prominent as in *Megalonyx*. Usually but a single mental foramen is present. In no. 456, however, a small opening is situated slightly above and posterior to the mental foramen of the right side. The horizontal limb of the ramus (fig. 6) is noticeably of less height, especially in the anterior region, and less robust than in *Megalonyx*. With the disappearance

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of the first tooth in *Nothrotherium* the deeply concave, outer wall of mandible between M_1 and M_2, occurring in *Hapalops* and *Megalonyx*, becomes greatly reduced and may be entirely absent as in no 166. There are frequently two foramina representing the postero-external opening of the dental canal in the Rancho La Brea species. In no. 208 two foramina are present on the left ramus and one on the right, an occurrence similar to that in a skull of *Hapalops longiceps*, no. 15523 Prin. Univ. Coll., while in no. 456 from Rancho La Brea there are two foramina on each side. The anterior foramen is situated on the outer surface of the ramus opposite the last inferior tooth and the second opening is at or slightly above the base of the ascending process.

The coronoid process arises well to the outer side of M_1 as in *Hapalops*, but it is relatively smaller than in the latter. It may be

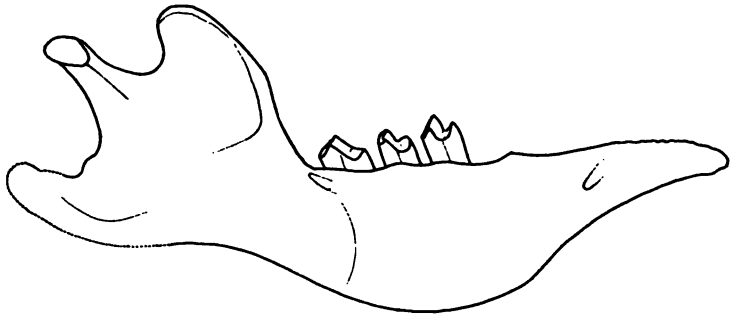

Fig. 6. *Nothrotherium shastense* Sinclair. Mandible no. 166 M. H. S. A., lateral view, × ⅓. Rancho La Brea Beds, California.

broad as in no. 456 or rather narrow. The sigmoid notch, due to the high position of the condyle above the tooth row in *Nothrotherium*, is relatively much smaller than in the Miocene genus. In no. 208 the condyle in dorsal view has much the shape seen in *Hapalops longiceps*. In no. 456 and no. 418 the condyle has a greater oblique diameter and is more slender than in no. 208. The ventral notch between condyle and angle is relatively wider than in *Hapalops*, while the angular process in some specimens from the asphalt extends posteriorly as a more slender hook than in *H. longiceps*. The angle of the jaw is much more slender in *Nothrotherium* than in *Megalonyx*. In *M. jeffersoni* the coronoid and angle are more nearly equally spaced on either side of the condyle than in the Rancho La Brea genus. The inferior border of the angle is deflected inward, forming a more pronounced shelf than in *Megalonyx*.

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MEASUREMENTS OF MANDIBLE*	N. shastense No. 166 M. H. S. A. Rancho La Brea	N. shastense No. 208 M. H. S. A. Rancho La Brea	N. shastense No. 418 M. H. S. A. Rancho La Brea	N. shastense No. 456 M. H. S. A. Rancho La Brea	N. shastense No. 636 M. H. S. A.† Rancho La Brea	N. shastense No. 637 M. H. S. A. Rancho La Brea	N. shastense No. 638 M. H. S. A. Rancho La Brea
Length from anterior end of symphysis to posterior end of condyle	275 mm.	277.1	*a*260.7	284.4	*a*267	.....	.....
Distance from anterior end of symphysis to anterior border of alveolus for $M_{\bar{1}}$	100.9	106.2	*a*96.8	104.7	100.3	.....	.....
Distance from posterior border of alveolus for $M_{\bar{1}}$ to posterior end of angle	121.2	134.6	*a*120	124.3	117.1	.....	.....
Greatest length of symphysis	90.4	90.3	*a*82.9	90.2	87	.....	.....
Greatest depth between $M_{\bar{1}}$ and $M_{\bar{2}}$, measured normal to tooth-row	56.6	60.6	54.2	56.1	53	61.3	61.6
Least height posterior to $M_{\bar{1}}$	43	47.5	42	44.8	38.6	46.8	47.5
Greatest height from angle to coronoid process	106.6	121.4	.....	*a*113.8	*a*101.7	.....	.....
Height of condyle above ventral border of angular process	79.7	.....	.....	.....	.....	26.4	26.8
Thickness of horizontal ramus at $M_{\bar{1}}$	27.2	29.3	26.7	28.2	25.3	.....	.....
Distance between inner alveolar borders of fourth cheek-teeth	33	30.7	.....	24.3	.....	.....	.....

* Where association of mandible with cranium is in doubt, the former is listed under a separate number.

† This mandible may belong to cranium 313.

a, approximate.

DENTITION

The dental formula in the Rancho La Brea *Nothrotherium* as in the Brazilian species is $\frac{4-4}{3-3}$. In possessing a reduced dentition, *Nothrotherium* differs markedly from the certainly known Miocene Megalonychidae and Planopsidae as well as from the Pleistocene genera, *Megalonyx* and *Megatherium*. All the teeth are considerably smaller than in *Megalonyx*. The external layer of cement on the teeth may be only as thick relatively as in *Hapalops*.

Superior Series.—The tooth-rows extend very nearly parallel, the palate increasing slightly in width between the fifth cheek-teeth. The teeth are more closely spaced than in Miocene genera. In the Rancho La Brea species the largest interspace occurs between the alveoli of M^4 and M^5. Reinhardt states that in the Brazilian species of *Nothrotherium* the teeth are equally spaced.

As in the various species of Santa Cruz ground-sloths the differentiation of the superior molariform teeth into a small M^2, much

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larger M^2 and M^4, and a M^5 greatly compressed anteroposteriorly, occurs also in *Nothrotherium* although the distinction between M^2 and M^3 or M^4 is not as marked in the former as in the latter. The teeth in *Nothrotherium* are noticeably more complex. This is indicated by the presence of distinct, median vertical grooves on the outer faces of M^2, M^3 and M^4, and to a less extent also on the inner faces. Even M^5, which is much more compressed anteroposteriorly than the other superior teeth, shows a distinct groove on the outer face and a much more faintly developed one on the inner. *Nothrotherium,* therefore, differs from *Megalonyx* in which such distinct lateral grooves are lacking on these teeth. In *Hapalops indifferens* the vertical grooving on the outer face of M^2, M^3 and M^4 has been noted by Scott in some specimens. In describing the corresponding teeth, as

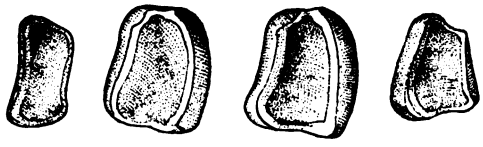

Fig. 7. *Nothrotherium shastense* Sinclair. Right, superior, dental series no. 208 M. H. S. A., occlusal view, natural size. First tooth to the right is M^2. Rancho La Brea Beds, California.

well as M^5, in *H. elongatus,* Scott[28] states that "the vertical grooving of these teeth appears to be very capriciously present or absent." Judging from the appearance of the occlusal surface, the outer compact layer of dentine in all the superior teeth of *Nothrotherium* is best developed on the anterior and posterior surfaces and least developed on the outer and inner sides. In M^2, M^3 and M^4 this layer is slightly thicker on the outer than on the inner surface. In M^5 the layer is thickest on the posterior face, while on the outer and inner faces it is of equal thickness.

M^2 is smaller than M^3 and M^4. Contrasted with the latter teeth, M^2 is relatively narrower transversely in *Nothrotherium* than in most species of *Hapalops.* It is relatively longer anteroposteriorly than in the latter genus. The tooth may be trapezoidal in shape, with anterior and posterior faces parallel as in no. 313, or these faces may converge to the outer side as in skull 208 (fig. 7). The anterior and posterior faces are nearly flat and the angles are well rounded. M^2 thus differs from

[28] Scott, W. B., *op. cit.,* p. 218, 1903.

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the corresponding tooth in *Megalonyx,* which Leidy[29] has described as follows: "The second upper molar in section (Pl. XVI, Fig. 9, *d*), is quadrate with rounded angles. Its inner and posterior sides are the greater, and are nearly equal; and the remaining sides are also nearly equal, and are planes. The inner side is slightly convex, and the posterior side is nearly a plane and is directed obliquely outward." On the occlusal surface the transverse valley between the anterior and posterior crests opens most broadly on the inner side in no. 208. In no. 313, on the other hand, where the transverse crests are parallel, the valley is of nearly the same width throughout.

M^3 and M^4 are very similar in general shape. M^3 may be slightly larger than M^4, but the corresponding measurements of these teeth are usually very close. In the greater number of species of *Hapalops,* M^3 is the largest of the molariform series, and this is true in general for the Santa Cruz Megalonychidae. In both teeth the anterior face is broadly convex and the posterior face concave. The anterior face rounds gradually to the external side; in other words, does not form a distinct angle with the outer side as in other cheek-teeth. The teeth do not narrow as much externally as in *Megalonyx jeffersoni,* in which respect they are more like *M. leidyi.* They lack the typical quadrate cross-section characteristic of the corresponding teeth of *Megatherium.* In M^3 and M^4 the anterior crest of the occlusal surface is decidedly beveled in front, and the cutting edge of this chiseled surface is usually worn into a crescent. The transverse valley is worn most broadly on the inner side. In both teeth the postero-internal angle of the occlusal surface is subjected to greatest wear. In several loose teeth of *Nothrotherium* from the asphalt beds, referable to M^3 or M^4, the outer face is seen to be noticeably concave in its longitudinal extent. This character apparently distinguishes these teeth from $M_{\bar{3}}$ and especially from $M_{\bar{2}}$.

M^5 resembles in its anteroposterior compression the corresponding tooth in *Hapalops* and in *Megalonyx.* It is approximately only one-half as long in that direction as the remaining superior cheek-teeth of *Nothrotherium.* The posterior face of M^5 in the species from the asphalt beds is very broadly concave and the concavity may become quite deep as in a young individual, no. 640. The nearly flat anterior face, which is of less width than the posterior face, may have a median strip defined by a slight groove on each side. The inner face may have a faint vertical groove near the anterior border, while the outer face is

[29] Leidy, J., *op. cit.,* p. 17.

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characterized by a well-marked median groove. On the occlusal surface there is no distinct valley formed, but the anterior edge is worn much lower than the posterior. This tooth differs decidedly from M^5 in *Megalonyx jeffersoni,* which Leidy[30] describes as follows: "The last molar is a smaller tooth than the preceding pair, but has nearly the same form in a reversed position, the base of the triangular section (Pl. XVI, Fig. 9, *a*) being outward. Its posterior side is transverse and is slightly concave; and the anterior side is convex and directed obliquely inward."

Inferior series.—With the loss of the first tooth in *Nothrotherium* the superior surface of the ramus directly in front of $M_{\bar{2}}$ is triangular in shape. The tooth-rows are relatively as far separated as in *Hapalops longiceps.* They are very nearly parallel or diverge slightly posteriorly. In the Pleistocene genus the characteristic features of the three posterior teeth in *Hapalops* have been accentuated. Scott

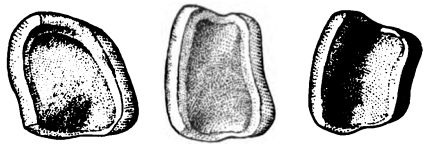

Fig. 8. *Nothrotherium shastense* Sinclair. Right, inferior, dental series no. 166 M. H. S. A., occlusal view, natural size. First tooth to the right is $M_{\bar{2}}$. Rancho La Brea Beds, California.

describes these teeth in *H. longiceps* as follows: ". . . $_{\bar{2}}$ and $_{\bar{3}}$ are transverse and rectangular, and their raised margins are quite deeply notched on the inner and outer sides by the transverse valley; $_{\bar{4}}$ is subcylindrical, as in most of the other species."[31]

In $M_{\bar{2}}$ and $M_{\bar{3}}$ the denser, outer layer of dentine of the tooth crown is least developed along the outer and inner sides. It is perhaps less developed on the outer than on the inner side. The layer is thicker on the anterior and posterior faces of the crown, and appears slightly better developed on the posterior face. The thickness of this more compact layer of dentine determines in part the structure of the occlusal surface. The outer and inner walls which are thinnest, resist wear less, and are worn down more rapidly than the anterior and posterior walls. The latter are therefore prominent on the wearing

[30] Leidy, J., *op. cit.,* p. 18.

[31] Scott, W. B., *op. cit.,* p. 182, 1903.

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surface as two transverse ridges with intervening valley excavated in the softer inner material of the crown. The type of wearing surface thus obtained resembles very much that in the larger teeth of *Megatherium,* but in that genus the outer compact dentine is thinner and the cement (on the anterior and posterior faces) relatively much thicker. In the Rancho La Brea *Nothrotherium* the cement is more evenly distributed on the crowns of the teeth, with a moderate increase on the anterior and posterior faces in some specimens. In *Megatherium* there is an excessive thickening of the cement on the anterior and posterior faces.

The complete length of the crowns of $M_{\bar{2}}$, $M_{\bar{3}}$ and $M_{\bar{4}}$ is exposed in the somewhat broken specimen, no. 418. The teeth are seen to reach the inferior wall of the ramus, which is very thin. In this ramus the inferior teeth diverge upward in their course from the base to the alveolar border. In longitudinal extent the crown of $M_{\bar{2}}$ is slightly concave posteriorly; $M_{\bar{3}}$ is practically straight posteriorly but slightly concave laterally; $M_{\bar{4}}$ evidently sloped posteriorly. $M_{\bar{3}}$ and especially $M_{\bar{2}}$ exhibit then a different longitudinal curvature from that shown by the third and fourth superior teeth.

In $M_{\bar{2}}$ (fig. 8) the transverse width of the anterior half is distinctly less than that of the posterior half. The transverse axis of the tooth is oblique to the long axis of the tooth-row. This tooth differs from the corresponding one in *Hapalops* and *Megalonyx* in the presence of median vertical grooves on the inner and outer faces. The anterior face is broadly concave while the posterior face is correspondingly convex. On the occlusal surface the anterior transverse ridge is nearly straight and may be beveled in front, while the posterior is crescentic and is beveled behind.

$M_{\bar{3}}$ is slightly larger than $M_{\bar{2}}$ and narrows more toward the inner side. It is transversely placed with reference to the long axis of the tooth-row. In occlusal view it resembles somewhat the third and fourth superior teeth, but is in reverse position. If the tooth is oriented so that the posterior margin of the occlusal surface corresponds to the anterior margin of the third or fourth superior tooth, the former can be distinguished by rounding less gradually toward the narrow lateral side. In other words, the third inferior tooth has all four angles better defined than those in the third and fourth superior teeth. This serves also to distinguish $M_{\bar{2}}$ from either M^{3} or M^{4}. The vertical grooves of the lateral faces appear, as a rule, to be more sharply defined than in $M_{\bar{2}}$, while the anterior half of the tooth is not as distinctly smaller

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transversely as the posterior half. $M_{\bar{3}}$ differs from the corresponding tooth of *Hapalops* and *Megalonyx* in the presence of well-marked lateral grooves. The anterior and posterior faces resemble those in $M_{\bar{2}}$.

MEASUREMENTS OF DENTITION	N. shastense No. 166 M. H. S. A. Rancho La Brea	N. shastense No. 208 M. H. S. A. Rancho La Brea	N. shastense No. 313 M. H. S. A. Rancho La Brea	N. shastense No. 632 M. H. S. A. Rancho La Brea	N. shastense No. 633 M. H. S. A. Rancho La Brea	N. shastense No. 634 M. H. S. A. Rancho La Brea	N. shastense No. 639 M. H. S. A. Rancho La Brea	N. shastense No. 640 M. H. S. A. Rancho La Brea	N. shastense No. 641 M. H. S. A. Rancho La Brea
Greatest length of superior molar series, alveolar measurement	61.6 mm.	62.8	61.5	57.5	62.3	65.4	.....	.....	.....
M^1, greatest anteroposterior diameter	12	12	12.1	*a*12.3	.....	12.4	10.4	9.7	9.9
M^1, greatest transverse diameter	12.9	13	13	*a*13.7	.....	14.3	10.5	11.2	11.9
M^2, greatest anteroposterior diameter	.....	13.3	13	*a*14	.....	13.8	.....	11	.....
M^2, greatest transverse diameter	.....	16.8	16.9	*a*16.8	.....	18.9	.....	14.4	.....
M^4, greatest anteroposterior diameter	13.2	13	12.8	13	.....	12.1	11.2	10.8	.....
M^4, greatest transverse diameter	17	17.2	17	17	.....	18.3	14.4	13.5	.....
M^5, greatest anteroposterior diameter	8.7	7.6	7.3	*a*7.8	.....	8.8	7.3	7.2	7.5
M^5, greatest transverse diameter	13.6	14.4	13.8	*a*12.9	.....	16	11.5	10.5	11.3
Greatest length of inferior molar series, alveolar measurement	57	54.7	No.636* 51.7	No.456 59	No.418 51.7	No.637 49.4	No.638 48.5		
$M_{\bar{3}}$, greatest anteroposterior diameter	13.6	.....	.....	13.6	13.9	*a*12.5	*a*11.8		
$M_{\bar{3}}$, greatest transverse diameter	16.5	.....	.....	17.6	15.9	*a*16.3	*a*16.2		
$M_{\bar{3}}$, greatest anteroposterior diameter	14.2	13.5	.....	14.1	*a*14.7	13.3	13.4		
$M_{\bar{3}}$, greatest transverse diameter	17	17.5	.....	18.4	16	16.4	16.4		
$M_{\bar{4}}$, greatest anteroposterior diameter	14	15	14	13.4	.....	14.5	*a*15		
$M_{\bar{4}}$, greatest transverse diameter	15.6	15.8	15	16.2	.....	15	14.8		

* This specimen may belong to cranium 313.
a, approximate.

The single tooth, no. 10495 Univ. Calif. Coll. Palae., of *Nothrotherium* previously described by the writer from Rancho La Brea, was assigned to the superior dentition chiefly on similarity of its cross-section to that of the second alveolus. It was remarked, however, that the Rancho La Brea specimen differed from no. 8702 from Potter

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Creek Cave in longitudinal curvature. The longitudinally concave, posterior face of no. 10495 and the distinctness of the angles of the occlusal surface relate this specimen much more closely with the second inferior tooth than with either the third or fourth superior teeth. The occlusal surface resembles also that of $M_{\bar{3}}$. No. 10495 is then either a second or third inferior tooth.

The last inferior tooth, which in *Hapalops* is more or less cylindrical in shape, retains the rounded internal side in *Nothrotherium*. It thus agrees with *Megalonyx* in differing markedly in shape from either $M_{\bar{2}}$ or $M_{\bar{3}}$. This tooth in *Megatherium,* although smaller and relatively longer anteroposteriorly than $M_{\bar{2}}$ and $M_{\bar{3}}$, is essentially of the same shape as the other inferior teeth. The transverse axis of $M_{\bar{4}}$ in *Nothrotherium* is directed obliquely to the long axis of the tooth-row, thus resembling *Hapalops* and *Megalonyx*. On the outer flattened face of this tooth a median vertical groove may be slightly defined as in no. 208, or well defined as in no. 456. In the presence of this groove, *Nothrotherium* differs from *Hapalops* and *Megalonyx*. The outer anterior and posterior corners of $M_{\bar{4}}$ are well rounded. The denser layer of dentine is best developed on the inner and posterior sides and least on the outer side. The border of the occlusal surface is least worn at the middle of the inner side and at the postero-external corner. Between the resulting prominences, the border is beveled posteriorly. In *Megalonyx* the occlusal surface of the corresponding tooth is somewhat similarly worn. It is described by Leidy as having "... a transverse valley, whose boundaries are most prominent at the antero-internal and postero-external angles."[32]

REVIEW OF SPECIES

In a former note[33] the writer briefly described a single skull of *Nothrotherium* without mandible from Rancho La Brea, which was referred to a new species, *N. graciliceps*. At that time the only other material of this genus available from the asphalt was a single tooth, no. 10435, in the palaeontological collections of the University of California. In a comparison of the Rancho La Brea *Nothrotherium* with *N. shastense* from Potter Creek Cave, it was inferred that the lower jaw in the former species was longer than in the latter. The principal difference, however, between the two forms was thought to rest in the shape of the last superior tooth.

[32] Leidy, J., *op. cit.*, p. 19.

[33] Univ. Calif. Publ. Bull. Dept. Geol., vol. 7, pp. 341–358, 1913.

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In addition to the skull material contained in the collections of the Museum of History, Science and Art of Los Angeles, there are also available for comparison five mandibles as well as fragments of mandibles of *Nothrotherium* from the asphalt beds. These specimens show a considerable range in size. No. 636 represents one of the smaller individuals and approximates very closely in size the fragmentary ramus, no. 8422 Univ. Calif. Coll. Palae., from Potter Creek Cave. The latter if anything is slightly smaller than no. 636. The differences between the specimens are slight. The tooth-row in no. 8422 is a trifle longer; the postero-external opening of the dental canal is small and the ascending portion of the ramus behind $M_{\overline{4}}$ is apparently a little thicker than in no. 636. On the whole the characters presented by the fragmentary ramus from Potter Creek Cave are hardly to be distinguished from those of the Rancho La Brea specimens.

Associated with the ramus of *N. shastense* from Potter Creek Cave are a number of teeth, one of which Sinclair[34] identified as a last superior tooth. He describes this specimen as follows: "It is a triangular tooth with the posterior side plane, the anterior convex, and the outer plane and meeting the posterior at a right angle."[35] A comparison of this tooth with the last superior alveolus of skull 15 from Rancho La Brea showed that the latter must have possessed a M^5 which differed markedly from Sinclair's specimen. This has been amply verified by the additional material now available. The shape of the tooth in the species from the asphalt beds is remarkably constant. It differs from the corresponding tooth, no. 8497 Univ. Calif. Coll. Palae., from Potter Creek Cave in (1) subtrapezoidal outline, (2) outer and inner sides of equal thickness, (3) posterior face concave transversely, (4) presence of vertical groove on outer face and faint vertical groove on inner face near anterior border, and (5) outer and anterior faces concave longitudinally.

The differences noted are undoubtedly great enough to separate the Rancho La Brea form as a distinct species, if Sinclair's specimen can be regarded with certainty as a last superior tooth of *Nothrotherium*. A critical re-examination of this tooth has convinced the writer that there are, however, serious objections to its being considered as such. As stated by Sinclair, no. 8497 (fig. 9) has been somewhat

[34] Sinclair, W. J., New mammalia from the quaternary caves of California, Univ. Calif. Publ. Bull. Dept. Geol., vol. 4, pl. 23, fig. 8, 1905.

[35] Sinclair, W. J., *ibid.*, p. 154.

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injured by rodents, especially toward the occlusal surface. The gnawed surfaces of the tooth do not seem to account entirely for the difference in size of the two ends: that is to say, the tooth narrows toward the occlusal face. This is considered as characteristic of immature individuals. It is apparent also that this tooth is exceptionally large in comparison with the remaining teeth of *Nothrotherium shastense*. Furthermore, there are several teeth in the collections from Potter Creek Cave which are not clearly referable to *Nothrotherium*, but belong perhaps to a small species of *Megalonyx*. In fact, Sinclair described a specimen, no. 8203, from the cave deposit which he identified tentatively as belonging to *Megalonyx wheatleyi*. With the fifth superior tooth of *M. jeffersoni* no. 8497 from Potter Creek Cave agrees in triangular shape but differs in size. The latter specimen

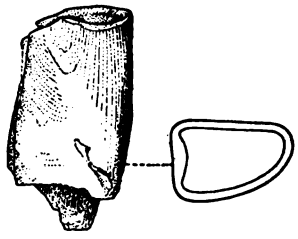

Fig. 9. *Megalonyx(?)*, sp. M^5, no. 8497, Univ. Calif. Coll. Palae., anterior view with outline of section through pulp-cavity, natural size. Potter Creek Cave, Shasta County, California.

lacks possibly "the slightly concave" posterior face noted by Leidy in *M. jeffersoni*, but this can only be regarded as a minor difference.

In a former note the writer considered specimen 8337 from Potter Creek Cave as probably representing an inferior tooth. The characters seen in occlusal view relate this specimen much more closely with $M_{\bar{2}}$ and $M_{\bar{3}}$ than with M^2 or M^4. The concave posterior face in its longitudinal extent is a character held in common by no. 8337 and $M_{\bar{2}}$ of *Nothrotherium* from Rancho La Brea. The tooth from Potter Creek Cave differs slightly from the second and third inferior teeth from the asphalt beds in having the four angles of the occlusal surface slightly more sharply defined.

While the comparatively large size of no. 8497 is in itself not sufficient reason for generic determination as other than *Nothrotherium*, in view also of its much closer resemblance to the fifth superior tooth of *Megalonyx* the identification with the latter is more probable than with *Nothrotherium shastense*. The fragmentary

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ramus, no. 8422, from Potter Creek Cave, presents but insignificant differences when contrasted with specimens from Rancho La Brea. In addition to no. 8497, a number of upper and lower teeth were regarded by Sinclair as pertaining to *N. shastense*. These specimens resemble closely in size and shape corresponding teeth of the Rancho La Brea species. Unless other characters favoring a specific separation of the Rancho La Brea material are revealed, *N. graciliceps* must be regarded therefore as synonymous with *N. shastense*.

Dr. O. P. Hay[36] has recently described as a new species, *Nothrotherium texanum*, a damaged skull possessing the superior dental series of one side but lacking the lower jaw. The specimen is reported to have come from northern Texas, presumably from Pleistocene deposits.

As indicated by Dr. Hay comparison between the Texas species and *N. shastense* from Potter Creek Cave is restricted to loose teeth found with the type ramus of the latter species. Of these, he considers specimens figured by Sinclair[37] as representing the second and third teeth. Specimen 8702 from Potter Creek Cave, represented in figures 3 and 3*a* of Sinclair's paper agrees very closely in size with the second superior tooth of *N. texanum*. Dr. Hay believes that the teeth of *N. texanum* can be distinguished, for in no. 8702 "both the front and the rear faces are convex in section, whereas both the second and the third teeth of *N. texanum* have the front face convex and the rear face concave."[38] In no. 8702 from Potter Creek Cave the posterior face is not entirely convex, for as is shown in section there is developed toward the outer side a slight but nevertheless distinct concavity. Furthermore, in teeth from Potter Creek Cave, representing either M^2 or M^4 of the superior dental series, the depth of this concavity may vary greatly.

Tooth 8337 from Potter Creek Cave, represented in figures 5 and 5*a* of Sinclair's paper, is regarded by Hay as being the third (M^4) of the superior series. In the previous note on the Rancho La Brea *Nothrotherium* the writer stated that no. 8337 is probably of the inferior dentition, a view which is still maintained.[39]

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[36] Hay, O. P., Descriptions of two extinct mammals of the Order Xenarthra from the Pleistocene of Texas, Proc. U. S. Nat. Mus., vol. 51, pp. 107–123, pls. 3–7, 1916.

[37] Sinclair, W. J., New mammalia from the quaternary caves of California, Univ. Calif. Publ. Bull. Dept. Geol., vol. 4, pl. 23, figs. 3, 3*a*, and 5, 5*a*, 1905.

[38] Hay, O. P., *ibid.*, p. 121, 1916. In the present paper the superior teeth of *Nothrotherium* regarded by Hay as second and third have been designated M^2 and M^4 respectively.

[39] *Vide supra*, p. 159.

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The fifth superior tooth, no. 8497, from Potter Creek Cave, referred to *Nothrotherium* by Sinclair, has been shown above to resemble *Megalonyx* much more closely. It undoubtedly does not pertain to the former genus. The characteristic features exhibited by this specimen cannot then be used as distinguishing *Nothrotherium shastense.*

It is evident from the above discussion that it is not possible to separate *N. texanum* from *N. shastense* on the basis of characters at present available.

Dr. Hay considers the Texas form as very closely related to the Rancho La Brea species of *Nothrotherium,* as indicated by a comparison with skull 15 contained in the collections of the Museum of History, Science and Art of Los Angeles and described by the writer in 1913. He remarks, however, that "One can not rely wholly on the differences which are seen in the two skulls for additional specimens may be intermediate."[40] The characters exhibited by the teeth of *N. texanum* fall easily within the range of variation of teeth in Rancho La Brea skulls. One of the important skull characters cited by Hay as distinctive of *N. texanum* is the structure of the pterygoid bulla. In the Texas specimen the bulla of each side is open wide below, in which respect it is in marked contrast to that of Rancho La Brea skulls. In the latter the pterygoid bullae when undamaged are always completely closed below with the exception of an elongate orifice on the inner ventral side. The pterygoid bulla in the skull of *Nothrotherium* from Brazil, described by Reinhardt, lacks even this internal opening and is apparently complete.

Judging from the damaged condition of the skull of *N. texanum* (the palate being severely injured and the pterygoid plates entirely broken away in that specimen), such fragile structures as the pterygoid bullae can hardly be expected to remain entire. It is then reasonable to suppose that the present appearance of these bullae in the Texas specimen is to be attributed to injury sustained during preservation. Dr. Hay is, however, of the opinion that the pterygoid bulla in *N. texanum* remained widely open below during the life of the individual. He states: "The bulla of *N. texanum* appears not to have had a floor. The pterygoids seem to form a wall which surrounds the cavity on both sides. On the median side the edge of the wall is partly intact, partly injured. On the outer side the wall comes down to a sharp thin edge which appears to be little if at all injured. In places the edge is certainly wholly natural. Such being the case

[40] Hay, O. P., *ibid.,* p. 121, 1916.

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the bulla is incomplete and is a cavity opening below by a mouth 30 mm. wide.''[41]

Of other skull characters considered by Hay as distinctive of *N. texanum* mention may be made of the dorso-ventral diameter or height of muzzle and combined width of the nasals. In contrast to no. 15 additional skulls now contained in the collections of the Museum of History, Science and Art of Los Angeles approach the Texas specimen much more closely in height of muzzle. This is particularly true of no. 166 in which the height is 49.2 mm. The combined width of the nasals in the latter skull corresponds almost exactly with that in *N. texanum.*

RELATIONSHIPS OF GENUS

In this paper it is proposed only to touch upon some of the most significant relationships of *Nothrotherium* as brought out in a study of the skull and dentition. The skeletal elements, associated with the skull material in the Museum of History, Science and Art of Los Angeles, furnish also a wealth of evidence concerning relation to Miocene and Pleistocene ground-sloths, and until the whole skeleton can be fully studied it is perhaps premature to enter on a final consideration of the systematic position of the genus.

The many resemblances between *Nothrotherium* and *Hapalops,* as shown by the foregoing comparisons, strongly support the view that the former genus is derived from *Hapalops* as held by Scott. More recently F. Ameghino[42] in a discussion of the Miocene relatives of *Nothrotherium* derives the genus from a Hapalops-like form. It is not clear which genus he considers closest in this Miocene ancestral relationship,[43] for in one phyletic scheme he derives *Nothrotherium* from *Trematherium* while in another he considers the genus as descending from *Xyophorus.* According to Scott, *Trematherium* is very imperfectly known, while *Xyophorus* is synonymous with *Hapalops.*

As already noted, the type of skull characteristic of *Nothrotherium* has deviated less from the more generalized type of the Miocene Megalonychidae than has *Megalonyx.* The differences between *Nothrotherium* and *Megalonyx,* which in many respects make them

[41] Hay, O. P., *ibid.,* p. 119, 1916.

[42] Ameghino, F., Notas sobre una pequeña coleccion de huesos de mamiferos procedentes de las grutas calcáreas de Iporanga en el Estado de São Paulo-Brazil, Revista do Museu Paulista, vol. 7, pp. 99–119, 1907.

[43] Ameghino, F., *ibid.,* pp. 105 and 119.

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very dissimilar in structure of skull, are to be considered as end-products of two widely divergent lines of evolution arising from more closely related forms in the Tertiary. The writer is thus entirely in accord with Scott, who states with reference to the Santa Cruz ground-sloths: "That *Hapalops* is nearly related to both *Nothrotherium* and *Megalonyx* is abundantly clear from a cursory examination of the skeleton, all parts of which are very similar to those of the two Pleistocene genera. In fact, there is every reason to believe that *Nothrotherium* was the direct descendant of some species of this genus."[44]

With a reduced dentition, *Nothrotherium* is not only more specialized than *Hapalops*, but is also more advanced than either *Megalonyx* or *Megatherium*. In a comparison of the two Pleistocene megalonychids, Ameghino states: "Pero en cambio, *Megalonyx* que tiene cinco dientes en cada lado aparece como una forma considerablemente mas primitiva que *Nothrotherium* que solo tiene cuatro."[45] Judging from the structure of the skull, the position of the molariform teeth in *Nothrotherium* undoubtedly corresponds to that of the four posterior teeth of *Megalonyx*. Thus a closer relationship between these genera than between *Nothrotherium* and *Megatherium* is indicated by the position of the molariform teeth. This resemblance extends also to the shape of these teeth.

In *Nothrotherium* and *Megalonyx* M^2 is smaller than M^3 or M^4 and this is usually true also for *Hapalops;* M^3 as a rule can be distinguished from M^4 by its slightly larger size; M^5 is compressed anteroposteriorly. In the inferior molariform series the principal character held in common (with slight modifications) by the three genera is the shape and position of M_4. In *Hapalops* this tooth is sub-cylindrical, while in *Nothrotherium* and *Megalonyx* it has essentially the same shape but with the outer side flattened. Further, in the three genera the transverse axis of M_4 is somewhat oblique to the long axis of the tooth-row. In *Megatherium* this tooth is quadrate in shape, and transverse in position, thus resembling the remaining inferior teeth.

CONCLUSIONS

Next to *Mylodon,* the genus *Nothrotherium* is the most abundant ground-sloth found at Rancho La Brea. It is represented by decidedly fewer individuals than is *Mylodon.* The occurrence of *Nothrotherium*

[44] Scott, W. B., *op cit.*, p. 181, 1903.

[45] Ameghino, F., *op. cit.*, p. 103.

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in the asphalt beds in greater numbers than *Megalonyx* is singular, considering the apparently more restricted range of the former genus in North America. There is reason for believing, however, that *Nothrotherium* flourished in California and Texas during a portion of the Pleistocene.

The species of *Nothrotherium* from the asphalt beds, originally considered by the writer as new, is now held to be identical with *N. shastense* Sinclair from Potter Creek Cave. Further investigation may justify a subspecific separation of the Rancho La Brea form, but at present there is not sufficient reason for a specific distinction from the Potter Creek Cave species.

The many characters held in common by *N. texanum* and *N. shastense* from Potter Creek Cave and Rancho La Brea suggest specific identity of the two forms.

Nothrotherium is very closely related to the Miocene genus *Hapalops*. Comparison between the two genera presents nothing which can be considered adverse to the view held by Scott, that *Nothrotherium* is the direct descendant from *Hapalops*. The Pleistocene genus shows several noticeable advances beyond the Miocene form in skull and dentition. The structure of the skull in *Nothrotherium* indicates a type which has deviated less than *Megalonyx* from a generalized skull characteristic of the Santa Cruz ground-sloths.

The great dissimilarity between *Nothrotherium* and *Megalonyx* in many characters of skull and dentition substantiates the views of Scott and Ameghino that these genera are the results of two divergent lines of evolution already separate in the Santa Cruz Miocene. The differences between the two Pleistocene genera are in many instances so great as to suggest a separation of subfamilies rather than genera. A close resemblance between the two forms is shown by the position and general shape of the molariform teeth, in which characters both genera are more closely related to each other than either is to *Megatherium*.

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FURTHER OBSERVATIONS ON THE SKULL STRUCTURE OF MYLODONT SLOTHS FROM RANCHO LA BREA

BY

CHESTER STOCK

UNIVERSITY OF CALIFORNIA PRESS

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INTRODUCTION

Opportunity has recently been afforded the writer to examine the very extensive series of mylodont skulls from Rancho La Brea contained in the collections of the Museum of History, Science and Art of Los Angeles. This series consists of thirty-two crania and a number of mandibles, for the most part well preserved, together with other skull material not in as favorable a state of preservation. The splendid collection at the Museum in Los Angeles rivals in wealth of material the great collections of Pampean ground-sloths in South American museums.

In examination of the Los Angeles series of skulls a number of interesting points presented themselves which were not touched upon, or were but little discussed, in the preliminary report by the writer[1] on the University of California series. Several of the skulls examined were found to differ in certain features from the broad type character-

[1] Stock, C., Skull and dentition of the mylodont sloths of Rancho La Brea, Univ. Calif. Publ., Bull. Dept. Geol., vol. 8, pp. 319–334, 1914.

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istic of *Mylodon harlani* from Rancho La Brea, and as these characters are apparently constant and cannot be satisfactorily shown to grade into the usual type of skull from the asphalt deposits, they are considered to represent a new subspecies. It may be possible to establish a series with uniform and perfect gradations between the narrow and broad types of skulls of *M. harlani* when the entire mylodont sloth collection is reviewed, but at present it seems necessary to make the distinction between the two forms.

I desire to acknowledge my thanks to Mr. Frank S. Daggett, Director of the Museum of History, Science and Art of Los Angeles, who not only very kindly allowed me to examine the ground-sloth material but rendered many personal favors during my stay at the Museum. I desire also to thank the other members of the staff for many courtesies shown me. The photographs of the skull of the new subspecies were taken at the Museum by Mr. L. E. Wyman.

CRANIUM

Of the thirty-two skulls of mylodont sloths contained in the Rancho La Brea collections of the Los Angeles Museum of History, Science and Art, by far the greater number range approximately between 460 mm. and 525 mm. in length (from anterior end of maxillary to posterior end of occipital condyles). None of the skulls attain the length of the Colorado specimen described by Professor Cockerell.[2] With the exception of three, possibly four crania, this series is composed of skulls having the general characteristics already discussed in connection with a similar series contained in the palaeontological collections of the University of California.

Specimens 642, 643, 646, and 695 [3] differ from the usual broad type of skull of *Mylodon harlani* from Rancho La Brea in the decidedly more slender cranium posterior to the postorbital processes. For skull 642 this is distinctly indicated in plate 3. In this respect they approach more closely the skull-form in *Mylodon garmani*, differing, however, in being much less slender. With the least width of the skull behind the postorbital processes as a convenient and suitable index of slenderness of the cranial case, a series can be established with gradations tending toward the broader type of skull. The speci-

[2] Cockerell, T. D. A., A fossil ground-sloth in Colorado, Univ. Colo. Studies, vol. 6, pp. 309–312, 2 pls., 1909.

[3] All numbers used in this paper, unless otherwise stated, are the catalogue numbers of specimens contained in the Rancho La Brea collections of the Museum of History, Science and Art of Los Angeles.

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men showing the greatest constriction is no. 646, while nos. 642, 643, and 695 show successively less constriction. The Nebraska skull described by Barnum Brown[4] is slightly more constricted than no. 646, but the actual difference is so small that it is negligible. In this arrangement, the skulls, including the Nebraska specimen, exhibit a variation in length of approximately only 30 mm.

In a former paper the writer[5] stated that the inflation of the muzzle in the mylodont skulls of the University of California series was similar to that in the Nebraska skull. This is true also for the greater number of skulls contained in the Museum of History, Science and Art of Los Angeles, as far as the actual diameter of muzzle is concerned. In proportion to the postorbital constriction, however, many of the skulls, including the slender types, are slightly less inflated at the muzzle than Brown's specimen.

The palate posterior to the fifth superior tooth is very narrow in the slender type of skull from Rancho La Brea. This character apparently does not depend on the slenderness of the cranium, since in *M. garmani* the palatal index is actually greater than in a broad skull of *M. harlani* (no. 21158 Univ. Calif. Coll. Palae.) of approximately the same length. Furthermore, in no. 21160 Univ. Calif. Coll. Palae., a narrow palate, which is 57.5 mm. in width, is associated with a broad cranium. The slender skulls again lend themselves to a gradational arrangement, which, however, is not the same as for the cranial index. No. 642 possesses the least width of palate posterior to the fifth tooth, the transverse diameter gradually increasing in skulls 646 and 643. The Nebraska skull in this character follows no. 643.

In none of the skulls contained in the Museum of History, Science and Art is the fifth superior tooth as little removed from the middle of the postpalatine notch as in Brown's specimen, or as far removed as in the skull described by Cockerell.

The flattened dorsal surface of the brain-case, outlined by the occipital crests, varies in width irrespective of the degree of slenderness of the cranium. In the slender skulls the width of this surface may be equal to or greater than in some of the broader types. In skull 707 the dorsal surface of the cranium is very wide, thus differing from the remaining skulls from the asphalt beds and resembling closely *Mylodon robustus* as figured by Owen.[6]

[4] Brown, B., Bull. Amer. Mus. Nat. Hist., vol. 19, pp. 569–583, pls. 50–51, 1903.
[5] Science, n.s., vol. 39, pp. 761–763, 1914.
[6] Owen, R., Description of the skeleton of an extinct gigantic sloth, etc. (London, 1842), pl. 3.

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MANDIBLE

A number of mandibles together with separate rami, some of which are directly associated with crania, are also in the collections of the Museum of History, Science and Art. These exhibit the degree of variation already discussed in connection with the University of California series of lower jaws.

In general the ramus decreases noticeably in height from the base of the coronoid process to the anterior side of the first lower tooth. Occasionally, as in no. 696, the height of the ramus in front of the first tooth is much greater, and resembles *M. garmani* and *M. robustus* as well as no. 21576 Univ. Calif. Coll. Palae. In no. 696, also, the inferior dental canal of the right ramus opens anteriorly by three foramina. The latter variation from the normal number of two occurs quite frequently, much more so than the occurrence of only a single opening. The greatest predental width of the mandible is always less than the distance between the first tooth of each side.

Unfortunately there are no mandibles directly associated with the three exceptionally slender skulls. An incomplete and badly worn mandible, showing the complete lower dentition on one side is, however, associated with no. 695. This specimen exhibits a remarkable abnormality in the presence, anterior to the first inferior tooth, of a distinct alveolus for an extra tooth. It is present only on the right ramus, where it is 9 mm. in advance of the normally placed first tooth. The alveolus measures 11 mm. in anteroposterior diameter by approximately 9 mm. transversely.

DENTITION

The thirty-two skulls contained in the Museum of History, Science and Art of Los Angeles exhibit a variation in the superior dentition similar to that noted in the University of California series, namely:

1. Skulls with four teeth on each side of the palate.
2. Skulls with four teeth on one side of the palate and five teeth on the opposite side.
3. Skulls with five teeth on each side of the palate.

The three, possibly four, slender skulls show the following variation: nos. 646 and 643 possess the normal number of five functional teeth on each side of the palate, no. 695 is an example of the second group, in which there are five teeth on one side and only four on the opposite side of the palate, and no. 642 had only four functional teeth on each side of the palate.

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This splendid series of specimens receives added importance in that it demonstrates completely how the first tooth of the superior series may disappear. In skull 694, a specimen originally of the third group, the alveolus for the first tooth is very well developed. On the left side of the palate the first alveolus was originally as well developed as on the right side. Around the border of the former alveolus an irregular, spongy growth of bone is formed which shows a tendency to grow toward the middle of the tooth-socket. That this actually takes place is well exhibited by no. 642, in which the closure of the first superior alveoli has progressed much further. In this skull the first alveolus of the left side is almost completely closed, while that on the right side has a shallow, crescentic opening along its lingual border.

No. 693 illustrates how the entire alveolus may be filled by a spongy growth of bone. The final stage is reached in no. 21156, Univ. Calif. Coll. Palae., for example, or in the Nebraska skull described by Brown, where the first superior tooth has entirely disappeared, its former presence being indicated by a scar in front of the second superior tooth.

It is interesting to note in this connection that somewhat similar observations on the closure of the first superior alveoli in South American mylodonts have been made by Burmeister,[7] who states:

> . . . Der Schädel des hiesigen Museums [a skull referred to *Grypotherium* and contained in the collections of the Museo Nacional at Buenos Aires] hat noch offene Alveolen im Oberkiefer; in dem von Reinhardt abgebildeten Schädel sind sie schon ganz mit Knochenmasse gefüllt, aber als Narben sichtbar geblieben.

Whatever the initial cause of the disappearance of the first superior tooth may have been, it is certain that in some cases the tooth was well developed at the time of its disappearance. It is conceivable that the tooth may have broken off during the life of the individual, an accident which might readily have occurred, considering the habits of the animal. A rapid growth of bone around the periphery of the alveolus may perhaps have prevented the tooth again becoming functional, and as a result resorption took place. It does not seem probable that such resorption was due to old age alone, although this may also have been a factor. In other skulls variation in size of the first tooth favors the idea that growth may in some individuals have been inhibited from the start. In no. 21158 Univ. Calif.

[7] Burmeister, H., S.-B. Akad. Berlin, p. 1132, 1886.

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Coll. Palae., for example, the first tooth, present only on the right side, was very diminutive. It is therefore not improbable that in some skulls the development of the first tooth may have been completely arrested.

As already stated, there are no mandibles directly associated with nos. 642, 643, and 646. A fragmentary lower jaw does, however, accompany no. 695, in which the fourth lower tooth is well preserved. This tooth is relatively as much elongated anteroposteriorly as that in the Nebraska specimen. It agrees also with Brown's specimen in the direction of the anterior and posterior lobes with reference to the long axis of the tooth-row. The anterior lobe has the usual oblique position with reference to that axis. The posterior lobe is placed transversely to the long axis of the tooth-row, in which respect the tooth not only agrees with $M_{\frac{4}{4}}$ of the Nebraska skull, but with corresponding teeth belonging to broader skulls from Rancho La Brea. The isthmus connecting the anterior and posterior lobes is broadly convex on its outer side, thus differing decidedly from the Nebraska specimen, in which a pronounced external fold is developed. In no. 696, a skull of the broad type, the external fold, or middle lobe, of the fourth inferior tooth is much more distinctly developed than in no. 695, although much less so than in no. 21156 Univ. Calif. Coll. Palae. The latter specimen approximates most closely the type of fourth inferior tooth seen in the Nebraska skull. An examination of twenty or more lower jaws in the Museum of History, Science and Art of Los Angeles, in various stages of completeness, failed to reveal a fourth lower tooth showing exactly the same stage of development as in the Nebraska specimen.

It may perhaps be urged that in no. 695 the abnormality shown by the presence of an extra tooth may have extended itself to the dentition as a whole, and thus invalidate any conclusion which may be drawn from a study of the fourth inferior tooth. The first inferior tooth in no. 695 appears to be more compressed anteroposteriorly, giving a subcircular rather than an oval or reniform section, which is the usual type in Rancho La Brea skulls. The remaining lower teeth show no characteristics which are not to be seen in other skulls, and apparently have developed normally.

Further modifications of the fourth inferior tooth, remarkable for its variability, may be noted. The anterior lobe of the tooth may be narrow or broad. It may have the usual, transverse position with reference to the long axis of the tooth-row as in no. 696 for example,

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or the inner half of this lobe may be reflected anteriorly, assuming a position more nearly at right angles to the long axis as in no. 645. The posterior lobe may be at right angles to the long axis, as already noted, or it may also be decidedly oblique, as in no. 645. In the latter specimen, which in length of skull exceeds somewhat *Mylodon garmani,* the fourth inferior tooth of the right side has practically the same anteroposterior length as in that species, while the tooth of the left side is somewhat shorter.

The third inferior tooth may occasionally be quite broad from the antero-internal to the postero-external side, as in no. 696. As a rule, the proportions of this tooth are more like those in the type of *M. harlani,* or the tooth may be narrower in Rancho La Brea skulls.

The fifth superior tooth generally is comparatively small. In no. 642 the anteroposterior diameter of this tooth is somewhat longer than is usual, and thus is more like the corresponding tooth in Brown's specimen.

MYLODON HARLANI TENUICEPS, n. subsp.

Plates 3 and 4

Type specimen no. 642, a skull contained in the Rancho La Brea collection of the Museum of History, Science and Art of Los Angeles.

Subspecific characters.—Skull more constricted behind postorbital processes and cranium more slender than in *M. harlani* from Rancho La Brea. Associated with these characters is a very narrow palate posterior to the fifth tooth. In possessing a slender cranium the subspecies approaches *M. garmani* more than does the typical *M. harlani* from the asphalt deposits, differing, however, from both in distinctly narrower palate. It resembles the Nebraska skull, no. 2780, Amer. Mus. Coll., described by Brown in degree of constriction behind the postorbital processes, but differs in having a narrower palate.

The extensive range of variation exhibited by the skull and dentition of *Mylodon harlani* makes it difficult to establish a type absolutely distinct from the parent species. It does not seem possible to establish a series showing gradations between one extreme, as represented by no. 642, and the other extreme as exemplified by no. 21158 Univ. Calif. Coll. Palae., because of difficulties encountered in endeavoring to bridge the gap between the narrow and broad types of skulls.

No. 644 was considered at first to supply a very necessary link in establishing a series of nearly perfect gradation, but after further comparison its affinities appeared to be rather more with the broader skulls. In least width of palate and least width of skull behind postorbital processes (see table of measurements[8]) no. 644 is undoubtedly

[8] Compare with table of measurements in Univ. Calif. Publ., Bull. Dept. Geol., vol. 8, p. 326, 1914.

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more like the broader skulls than are the three slender specimens. No. 644 belongs apparently to a younger individual than those having the slender skulls, judging from the closure of the coronal and parieto-squamosal sutures. These sutures are hardly, if at all, discernible in the latter specimens. It may be possible that the sutures have closed for other reasons than age alone.

An objection to the separation of a new subspecies may be raised by the apparent inconstancy in *Mylodon harlani* of the variations given as characteristic of *M. h. tenuiceps.* No. 21160 Univ. Calif. Coll. Palae. has been cited as an example in which a small palatal index is associated with a broad cranium, while in Brown's specimen from Nebraska a small cranial index is associated with a comparatively broad palate posterior to the fifth tooth. It is also worth noting that in *M. garmani,* although the cranial index is very small, the palate is very broad. In establishing the subspecies the writer has been impressed by the lack of continuity in the gradations exhibited by the Rancho La Brea series when the two characters under consideration are taken in combination, rather than by the variability of the characters taken separately.

The writer would not hesitate to include the Nebraska skull described by Brown in this subspecies, and thus render a new name unnecessary, were it not for the following considerations:

1. The differences between *M. h. tenuiceps* and *M. harlani* contained in the Museum of History, Science and Art of Los Angeles are based on a comparison between individuals in which the coronal and parieto-squamosal sutures have closed. In the Nebraska skull the coronal suture is still distinctly to be seen. Another apparently characteristic feature of a more advanced age, which is fairly constant in the Rancho La Brea series, is the degree of pitting of the palate. In the typical slender skulls this is distinctly more developed than in the Nebraska specimen. In no. 695 the palate is too badly worn to indicate this with certainty.

2. In the three, possibly four skulls, which are considered to represent *M. h. tenuiceps,* the palate posterior to the fifth tooth is narrowed decidedly. This portion of the palate in Brown's specimen is more as in the broader types of skulls from Rancho La Brea.

The amount of variation exhibited by the fourth inferior tooth in specimens of the Museum of History, Science and Art of Los Angeles support the previous contention that it is unsafe to base any primary specific characters on this tooth. It must be admitted, how-

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ever, that in the great series at Los Angeles there is no indication of a fourth inferior tooth having exactly the same development as in Brown's specimen.

It appears undesirable to interpret the characters, given as diagnostic of the subspecies, as of sex value on account of the obvious difficulty of explaining the apparent preponderance of one of the sexes.

The slender skulls, represented by nos. 642, 643, and 646, as contrasted with a typical broad skull of *M. harlani*, may be comparable to dolichocephalic and brachycephalic types in other groups of animals.

MEASUREMENTS OF SKULL

	M. h. tenuiceps No. 642, M. H. S. A. Rancho La Brea	M. h. tenuiceps No. 643, M. H. S. A. Rancho La Brea	M. h. tenuiceps No. 646, M. H. S. A. Rancho La Brea	M. h. (?)tenuiceps No. 695, M. H. S. A. Rancho La Brea	M. harlani No. 644, M. H. S. A. Rancho La Brea
CRANIUM					
Length from anterior end of maxillaries to posterior end of occipital conyles	495. mm.	486.4	471.5	*a*459.4	*a*492.8
Length of palate from anterior end of maxillaries to post-palatine notch	219.	217.6	213.2	.....	*a*216.3
Greatest width of maxillaries, measured across palate anterior to first teeth	136.4	*a*138.6	.....	.....	125.4
Least width of palate posterior to fifth tooth	52.7	57.4	*a*55.5	.....	67.
Least distance across ventral margin of pterygoid plates	.....	111.7	.....	.....	.....
Greatest width of muzzle	133.5	*a*135.	.....	*a*131.	*a*131.
Least width behind postorbital processes	94.6	97.7	91.7	*a*100.	108.
Mastoid width above stylohyal processes	184.5	*a*184.	178.	*a*167.7	184.5
Greatest width across occipital condyles	131.	132.	118.5	*a*122.8	128.2
Height, measured from plane of basioccipital to dorsal plane	134.8	*a*131.8	129.6	128.	138.2
Least distance from fifth superior tooth to middle of post-palatine notch	45.6	47.3	50.8	.....	53.4
MANDIBLE					
Greatest length of symphysis	.....	.....	.....	*a*92.7	.....
Greatest predental width	.....	.....	.....	98.	.....
Depth of ramus between third and fourth inferior teeth, measured normal to inferior margin	.....	.....	.....	*a*83.	.....

a, approximate.

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MEASUREMENTS OF DENTITION

	M. h. tenuiceps No. 642, M. H. S. A. Rancho La Brea	M. h. tenuiceps No. 646, M. H. S. A. Rancho La Brea	M. h. (?)tenuiceps No. 695, M. H. S. A. Rancho La Brea	M. harlani No. 644, M. H. S. A. Rancho La Brea
M^2, anteroposterior diameter	*al*33.5 mm.	.....	.....	*a*31.8
M^2, transverse diameter	*al*18.3	.....	.....	20.
M^3, anteroposterior diameter	*a*28.6	*a*23.2	.....	28.3
M^3, transverse diameter	*a*24.3	*a*20.3	.....	23.
M^4, anteroposterior diameter	22.	*a*22.4	.....	.....
M^4, transverse diameter	23.3	23.7	.....	.....
M^5, anteroposterior diameter	*a*27.3	22.3	.....	25.6
M^5, transverse diameter	*a*20.	18.	.....	22.4
Length of superior series, from anterior end of first alveolus to posterior end of fifth alveolus	146.5	*a*137.	.....	.....
Length of superior series, from anterior end of second aveolus to posterior end of fifth alveolus	119.6	110.8	.....	120.6
M_1, anteroposterior diameter	.....	.....	*a*14.5	.....
M_1, transverse diameter	.....	.....	*a*15.4	.....
M_3, anteroposterior diameter	.....	.....	25.7	.....
M_3, transverse diameter	.....	.....	20.2	.....
M_3, diameter of occlusal surface normal to greatest diameter	.....	.....	17.	.....
M_4, anteroposterior diameter	.....	.....	52.	.....
M_4, greatest diameter of anterior lobe	.....	.....	*a*28.7	.....
M_4, greatest diameter of posterior lobe	.....	.....	*a*19.7	.....
Length of inferior series, alveolar measurement	.....	.....	130.4	.....

a, approximate. *al*, alveolar measurement.

CONCLUSIONS

The following additional facts have been noted with reference to the mylodont skull series from Rancho La Brea:

Three, possibly four, crania contained in the Museum of History, Science and Art of Los Angeles, are recognized as representing a form subspecifically distinct from typical *Mylodon harlani*.

These crania differ from *M. harlani* of Rancho La Brea in exhibiting in combination a rather narrow brain-case with a narrow palate posterior to the fifth tooth.

The Nebraska skull described by Brown can not be referred to the new subspecies from Rancho La Brea, since its characters, although in certain respects approaching those of the latter, are still quite distinct. The Nebraska specimen presumably represents *Mylodon harlani*, but may belong in a subspecies distinct from the two known to occur at Rancho La Brea.

Transmitted December 23, 1916.

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642 M. H. S. A., inferior
Rancho La Brea Beds, Cali-

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JUN 20 1918

SYSTEMATIC POSITION OF SEVERAL AMERICAN TERTIARY LAGOMORPHS

BY
LEE RAYMOND DICE

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INTRODUCTION

A study of the teeth of many lagomorphs, including both Recent and extinct forms, has shown that the enamel patterns furnish remarkably constant diagnostic characters. Each species commonly possesses a distinct tooth pattern and there are usually striking differences separating the genera. The most important characters are the number and form of the re-entrant angles of $P_{\overline{3}}$, the number of re-entrant angles of $P^{\overline{2}}$, and the depth and amount of crenation of the re-entrant angles of the upper molariform teeth.

Until a few years ago nearly all the Leporidae were included in the genus *Lepus*, but more recently the family has been divided into a number of distinct genera. A critical study of two fossil species previously placed in the genus *Lepus* shows that they cannot be retained in that genus as it is now restricted, and new genera are therefore proposed for their reception.

Another species of lagomorph previously referred to *Palaeolagus* is shown by the characters of the enamel patterns to belong to the family Ochotonidae, but it differs from any known form in that family, and for it also a new generic name is proposed.

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The new genera are based largely on the characters of the teeth, particularly on differences in the enamel patterns, but, where parts of the skeleton are known, decided differences from other lagomorphs are found also.

The material on which the following descriptions are based is located in the Palaeontological Collections of the University of California. Thanks are due Dr. J. C. Merriam for advice and criticism during the progress of the study. The drawings of the teeth have been made with a camera lucida on a microscope magnifying twelve diameters, and the pattern of each tooth has been drawn separately, from a point of view parallel to the length of the tooth.

ARCHAEOLAGUS,[1] new genus

Type species *Lepus ennisianus* Cope

Abundant in the Upper Oligocene John Day beds of Oregon. Besides the descriptions[2] and figures[3] given by Cope there have been available in this study a considerable number of specimens from the John Day beds now in the palaeontological collections of the University of California.

Fig. 1. *Archaeolagus ennisianus* (Cope). Left upper molariform teeth, × 3. Univ. Calif. Coll. Vert. Palae. no. 1501. John Day beds, Oregon.

P^2 with a shallow groove on its anterior face. Upper molariform teeth with interior re-entrant angles not crenated and not extending as far as half across the crowns. On these teeth there are often enamel crescents exterior to the outer ends of the re-entrant angles, and sometimes the backs of the crescents connect with the outer side of the teeth. P_3 shows an exterior re-entrant angle extending about half way across the tooth. Anterior to this is a shallow groove, which is also on the outer surface. The inner border of the tooth is without re-entrant angles, differing in this respect from *Palaeolagus*. M_3 is imperfectly divided into two columns by a deep exterior re-entrant angle. There is very little cement on any of the teeth.

[1] ἀρχαῖος, primitive; λαγῶς, hare.

[2] Cope, E. D., Bull. U. S. Geol. Sur. Terr., vol. 6, pp. 385–386 (1882).

[3] Cope, E. D., Tertiary vertebrata, Rept. U. S. Geol. Surv. Terr., vol. 3, bk. 1, pl. 64, figs. 11 and 11*a*; pl. 66, figs. 29*a*, 29*b*, and 29*c* (1884).

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The posterior part of the jaw is very different in shape from that of any living lagomorph. The region for the attachment of the masseter muscle is very weakly developed, and, as stated by Cope,[4] the masseteric fossa is entirely posterior to the tooth row.

Fig. 2

Fig. 3

Fig. 2. *Archaeolagus ennisianus* (Cope). Left lower molariform teeth (except $M_{\bar{3}}$), × 3. Univ. Calif. Coll. Vert. Palae. no. 1267, × 3. John Day beds, Oregon.

Fig. 3. *Archaeolagus ennisianus* (Cope). Right $M_{\bar{3}}$ and $M_{\bar{3}}$, × 3. Univ. Calif. Coll. Vert. Palae. no. 339, × 3. John Day beds, Oregon.

The skull indicates that the John Day animal had approximately the size of *Sylvilagus floridanus*. However, the skull is more slender, and the braincase has a much smaller capacity than that of any Recent rabbit.

HYPOLAGUS,[5] new genus

Type species *Lepus vetus* Kellogg[6]

One jaw is known from the Middle Miocene, Virgin Valley beds. Two jaws, one of them the type specimen, and one upper molar are known from the Pliocene, Thousand Creek beds. Both localities are in Humboldt County, Nevada.

In this genus $P_{\bar{3}}$ has two exterior re-entrant angles, neither of which extends over half way across the tooth. The posterior angle is much deeper than the anterior. There are no grooves on the inner surface of the tooth. The upper molar has the re-entrant angle ex-

Fig. 4

Fig. 5

Fig. 4. *Hypolagus vetus* (Kellogg). Left lower molariform teeth, × 3. Univ. Calif. Coll. Vert. Palae. no. 12567. Thousand Creek beds, Nevada.

Fig. 5. *Hypolagus vetus* (Kellogg). Upper molariform tooth, × 3. Univ. Calif. Coll. Vert. Palae. no. 21868. Thousand Creek beds, Nevada.

tending about half way across the crown and the enamel in the angle is coarsely folded. Cement is well developed on the teeth, particularly on the specimens from Thousand Creek.

[4] Cope, E. D., Bull. U. S. Geol. Surv. Terr., vol. 6, p. 385 (1882).

[5] ὑπό, under; λαγῶς, hare.

[6] Kellogg, L., Univ. Calif. Publ. Bull. Dept. Geol., vol. 5, p. 436, fig. 20 (1910).

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The posterior re-entrant angle of $P_{\bar{3}}$ in the Virgin Valley specimen is somewhat different from that in the type specimen, and the shape of $P_{\bar{3}}$ differs in the two. There are also some differences in the comparative size of various other teeth. It may be that the Virgin Valley form should be placed in a separate species, but the amount of material now at hand is too scanty to permit a satisfactory determination of this point.

$P_{\bar{3}}$ in *Hypolagus* differs from the corresponding tooth in *Archaeolagus* in being proportionally shorter and broader, although the enamel pattern is very similar in the two genera. *Hypolagus* further differs from *Archaeolagus* in having the re-entrant angles of the molars coarsely folded, whereas they are simple in the John Day species. Also, in *Hypolagus* the region of the jaw for the attachment of the masseter muscle is well developed, as in modern rabbits, and is not weak, as in *Archaeolagus.*

In the characters of the teeth and skeleton *Hypolagus* is in general more simple than *Lepus,* and may be considered a form near the probable ancestor of that genus as well as of several other modern genera. *Archaeolagus* is a form much more primitive than *Hypolagus,* and might well have been its progenitor.

OREOLAGUS,[7] new genus

Type species *Palaeolagus nevadensis* Kellogg[8]

A single specimen, consisting of part of a lower jaw and the teeth, except $M_{\bar{3}}$, is known from the Middle Miocene, Virgin Valley beds of Humboldt County, Nevada.

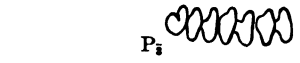

Fig. 6. *Oreolagus nevadensis* (Kellogg). Lower molariform teeth (except $M_{\bar{3}}$), × 3. Univ. Calif. Coll. Vert. Palae. no. 12575. Virgin Valley beds, Nevada.

The form is evidently a lagomorph, as the lower molar teeth are formed of two columns, one posterior to the other. The species, however, seems to have closer affinities to the Ochotonidae than to the Leporidae, for the posterior column of the molariform teeth is attached to the anterior column in a narrow neck, rather than by a broad union extending nearly across the tooth, as in the Leporidae.

[7] ὄρος, mountain; λαγῶς, hare.

[8] Kellogg, L., Univ. Calif. Publ. Bull. Dept. Geol., vol. 5, p. 435, figs. 19*a* and 19*b* (1910).

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$P_{\bar{3}}$ has a re-entrant angle originating on the antero-exterior border of the tooth and extending about half way across. This tooth is relatively much smaller than is usual in lagomorphs, being little, if any, larger than the anterior column of $P_{\bar{4}}$. Its enamel pattern, also, is very peculiar, differing radically from that of any other known lagomorph.

Oreolagus must be considered an aberrant ochotonid, probably not ancestral to any known species, which appeared in North America long before the appearance here of the modern genus *Ochotona*.

Transmitted December 20, 1916.

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NEW FOSSIL CORALS FROM THE PACIFIC COAST

BY

JORGEN O. NOMLAND

UNIVERSITY OF CALIFORNIA PRESS
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INTRODUCTION

In an earlier paper[1] the writer has summarized the known corals of the Pacific Coast Cretaceous and Tertiary. More recently a large and important coral fauna has been described by Dr. T. W. Vaughan[2] from the Pliocene of Carrizo Creek in the southern part of California. Since the appearance of these publications a few new species have been discovered and other forms have become available. These species are described in the present paper.

Heretofore by far the greater proportion of corals have been described from the Tejon Eocene. It is worthy of note that two of the new species here described are from the Oligocene. Several other forms are known to be present in the Oligocene faunas, but the only material obtained up to the present time is not sufficient for specific description.

[1] Nomland, J. O., Corals from the Cretaceous and Tertiary of California and Oregon, Univ. Calif. Publ. Bull. Dept. Geol., vol. 9, no. 5, 1916.

[2] Vaughan, T. W., The Reef-Coral Fauna of Carrizo Creek, Imperial County, California, and its Significance, U. S. Geol. Surv., Prof. Paper 98, 1917.

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ASTRANGIA BOREAS, n. sp.

Plate 5, figures 2*a*, 2*b*, 2*c*

Type, no. 11324, Univ. Calif. Coll. Invert. Palae. From the Treadwell mine, Alaska.

Colony with base somewhat encrusting but extending upwards as irregular, short branches; reproduction by basal expansion and also by buds arising irregularly from the sides and within the calices of older corallites; corallites, frequently narrow near base, becoming wider above. Costae almost obsolete, smooth, on some portions visible nearly to the base, of the same number as the septa. Septa numerous, thin, dentate, lateral faces with few small granules, arranged in four or five cycles, of which the first two reach the columella, some of the septa of the later cycles fused to the earlier cycles without regularity. Calice deep, nearly circular. Wall rather thin. Columella well developed, spongy, rather small in proportion to the size of the calice. Greater transverse diameter of one of the largest calices of type, 15.5 mm.; lesser transverse diameter, 12.5 mm.; height of corallites varies greatly.

Occurrence.—A letter dated June 20, 1890, sent to Professor Joseph LeConte by the collector, M. A. Knapp, gives the following description of the locality at which the specimens were found, "On the quartz croppings of this (Treadwell mine) ledge, 175–180 feet above sea-level and about 500 yards from shore." Pleistocene (?), Douglas Island, southeastern part of Alaska.

ASTRANGIA GRANDIS, n. sp.

Plate 5, figures 5*a*, 5*b*

Type, no. 11325, a well preserved specimen in Calif. Acad. Sci. Coll. from locality 76, at Waldorf Asphalt mine, in hills about four or five miles south of Guadalupe, Santa Barbara County, California.

Corallum incrusting a fragment of rather soft shale saturated with asphalt; base expanding as a thin coating; corallites large, new ones apparently arising from basal expansion of the older; calicular fossa deep, elliptical. Externally ornamented by distinct, coarsely granulate somewhat angular costae extending to the base; interspaces wide, occasionally with a small granulate rib. Wall rather thin, slightly thickened internally. Septa thin, coarsely dentate; lateral faces with numerous pointed granules; in about five incomplete cycles, of which the first three reach the columella; fourth cycle fused to the earlier cycles; fifth small, free. Columella rather dense, not large in propor-

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tion to size of the calices, composed of fascicles with additions from the septal ends. Dimensions: greater transverse diameter of calices, about 19 mm.; lesser transverse diameter of calices, 13 mm.; altitude of corallites, approximately 17 mm.

Occurrence.—Middle Fernando, Pliocene, Guadalupe, Santa Barbara County, California.

ASTREOPORA OCCIDENTALIS, n. sp.

Plate 5, figures 1*a*, 1*b*, 1*c*

Type, no. 11323, in Univ. Calif. Coll. Invert. Palae., from ocean beach near Newport, Oregon. Material purchased from John Lumis, Ashland, Oregon.

Corallum a water-worn pebble largely replaced by chalcedonic quartz; upper surface of corallites not present, but internal structure remarkably well preserved. Corallites small, 1.25 to 1.50 mm. in diameter, long and comparatively straight, usually circular but sometimes subcircular in outline, surrounded by a large proportion of very cellular exotheca. Wall thin with distinct but not numerous perforations, dictinctly marked off from surrounding exotheca. Septa twelve, short and thick, extending uniformly throughout the length of corallites in two cycles of which the primary is much more prominent, a third cycle of septa represented by costules; along the inner margin of the first cycle of septa nodes occurring at regular intervals project on the sides and inward, giving a dentate appearance; where these are cut in cross-section pali seem to be present on the inner ends of the primaries; interseptal loculi wide, thin tabulae well-developed, .75 to 1 mm. apart; spaces between the tabulae open. Columella absent. Dimensions of corallites: diameter from .8 mm. to 1.1 mm.; length not known.

Occurrence.—On ocean beach near Newport, Oregon. Probably from the Tertiary deposits in that vicinity.

CARYOPHYLLIA OREGONENSIS, n. sp.

Plate 5, figures 3, 4

Type specimen, no. 11326, in invertebrate palaeontology collections of California Academy of Sciences, San Francisco. From Smith's Point, Astoria, Oregon.

Corallum short, subflabellate, elliptical in cross-section, base subacute with attachment scar visible; calicular fossa deep; wall thin and fragile. Costae prominent, sharp, coarsely granular, corresponding to all the septa; those corresponding to the twelve principal septa much

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larger than the others; intercostal grooves narrow. Septa forty-eight, faces granulate, irregularly bent, the upper margins projecting considerably above the corallum wall, giving a saw-tooth appearance; in four complete cycles, of which the first two reach nearly to the columella, fourth cycle short, free. Pali thin and indistinct, attached to the septa, before the margins of the first three cycles, which are of nearly the same diameter. Columella consisting of a few heavy scattered twisted trabeculae. Dimensions of type, which is a small specimen: maximum transverse diameter, 9.5 mm.; lesser transverse diameter, 6 mm.; height, approximately 8 mm.

Three other fossil corals of this genus have been described from the Pliocene and Pleistocene of the Pacific Coast—*Caryophyllia arnoldi* Vaughan, *Caryophyllia californica* Vaughan, *Caryophyllia pedroensis* Vaughan. The species here described differs from these forms greatly.

Occurrence.—In a fine soft black shale, on street grade above Smith's Point, northwestern Oregon; Astoria Series, Oligocene.

DENDROPHYLLIA CALIFORNIANA, n. sp.

Plate 5, figures 6*a*, 6*b*

Type, no. 11190, Univ. Calif. Coll. Invert. Palae. From locality 1131, one-half mile south-southwest of the town of Walnut Creek, Contra Costa County, California.

Corallum consisting of irregularly branching stems. Calices numerous but not crowded, subcircular, approximately equal in size, rising only slightly above the surface, of medium depth, occurring apparently on all sides of the stems without definite order of arrangement. Wall rather thin, spongy. Costae granulate, nearly equal in size, well developed, but due to the large number of pores in the wall ribs may not be continuous but interrupted or deflected. Septa about forty-eight, granulate, rather heavy, arranged in four cycles, of which the first three reach the columella, fourth cycle regularly fused to the third. Columella spongy, occupying a large part of the calice. Dimensions of calices, about 6.5 mm.

This species has some of the characters of *Dendrophyllia hannibali* Nomland, which also occurs in the Oligocene of the Pacific Coast. It may, however, readily be distinguished from that form by the more numerous calices, finer costae, and the large spongy columella. From *Dendrophyllia tejonensis* Nomland of the Tejon Eocene it differs in the spongy wall, greater number of calices, and larger columella.

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Occurrence.—At locality 1131, near base of Agasoma gravidum zone, Oligocene.

This form occurs at the type locality of *Siderastrea clarki* Nomland and is associated with such characteristic Oligocene species as *Agasoma gravidum* (Gabb), *Antigona mathewsonii* (Gabb), *Ancellaria fishii* Gabb, *Dosinia mathewsonii* Gabb, *Dosinia whitneyi* (Gabb), *Molopophorus biplicatus* Gabb, *Mytilus mathewsoni* Gabb, *Fusinus* (*Priscofusus*) *hecoxi* Arnold.

BALANOPHYLLIA, sp.

It is of interest to note that specimens of *Balanophyllia* have been discovered recently in beds of middle Fernando, Pliocene, at Fugler Point, eight miles southeast of Santa Maria, Santa Barbara County, California. This genus has heretofore been unknown in the Tertiary deposits of the Pacific Coast later than the Oligocene. This form is associated with a large typical Fernando fauna.[2]

ASTORIA OLIGOCENE CORALS

In the Oligocene of the Astoria group of southwestern Washington several species of corals are present, but the material is only generically identifiable. These are found associated with *Dendrophyllia hannibali* Nomland or in the same series of beds as that species. The following forms, occurring with a large molluscan fauna, have been determined: *Balanophyllia,* sp., *Flabellum,* sp., *Paracyathus,* sp., *Pocillopora* (?), sp., *Sphenotrochus* (?), sp., *Trochocyathus* (two species).

[2] See U. S. Geol. Surv. Bull. 322, p. 60.

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EXPLANATION OF PLATE 5

Fig. 1*a*. *Astreopora occidentalis*, n. sp. Longitudinal view of polished surface Univ. Calif. Coll. Invert. Palae., no. 11323. × 2.

Fig. 1*b*. *Astreopora occidentalis*, n. sp. Cross-section view of polished surface of same specimen as figure 1*a*. × 7.

Fig. 1*c*. *Astreopora occidentalis*, n. sp. Cross-section of specimen shown in figure 1*a*. × 2.

Fig. 2*a*. *Astrangia boreas*, n. sp. General view of type specimen. Univ. Calif. Coll. Invert. Palae. no. 11324; Pleistocene(?). Natural size.

Fig. 2*b*. *Astrangia boreas*, n. sp. View of specimen seen in figure 2*a*, showing denticles on septal margins. × 2.

Fig. 2*c*. *Astrangia boreas*, n. sp. Enlarged calicular view of specimen seen in figure 2. × 2.

Fig. 3. *Caryophyllia oregonensis*, n. sp. Upright view of type specimen. Calif. Acad. Sci. Coll. no. 11326; Oligocene. × 2.

Fig. 4. *Caryophyllia oregonensis*, n. sp. Cross-section view of a small specimen. × 2.

Fig. 5*a*. *Astrangia grandis*, n. sp. Enlarged calicular view of type specimen. Calif. Acad. Sci. Coll. no. 11325; Fernando Pliocene. × 2.

Fig. 5*b*. *Astrangia grandis*, n. sp. General view of type. Natural size.

Fig. 6*a*. *Dendrophyllia californiana*, n. sp. Upright view of type. Univ. Calif. Coll. Invert. Palae. no. 11190. Oligocene. Natural size.

Fig. 6*b*. *Dendrophyllia californiana*, n. sp. Enlarged view of calices of type specimen seen in figure 6*a*. × 3.

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1a

2b

2a

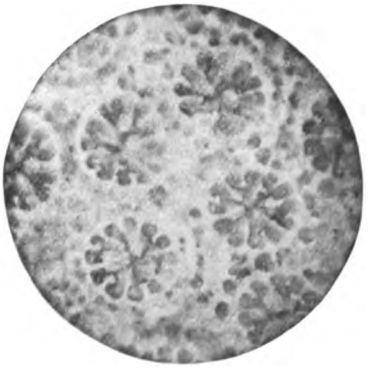
4

5b

3

5a

6a

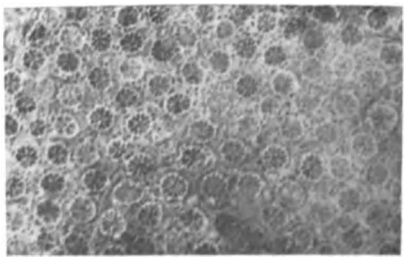


1b

2c

6b

1c



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Vol. 10, No. 14, pp. 191-254, 2 text-figs., pls. 6-12 Issued April 19, 1917

THE ETCHEGOIN PLIOCENE OF MIDDLE CALIFORNIA

BY
JORGEN O. NOMLAND

UNIVERSITY OF CALIFORNIA PRESS
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INTRODUCTION

The Etchegoin group of California has for a number of years attracted the attention of palaeontologists and geologists because of its somewhat uncertain position with respect to the other divisions of the late Tertiary. Especially has it been difficult to ascertain the time relation between these beds and the Pliocene sections along the outer side of the Coast Ranges south of San Francisco. The Etchegoin has been considered the equivalent of the San Pablo Miocene by certain writers, while by others it is held to represent the stage of the Purisima and Merced Pliocene. Although excellent work has been done on the Etchegoin invertebrate fauna by several investigators, the difficulties of pioneer work have made it impossible to secure the large representation now available to the writer. The determination of the age of this group has recently been facilitated by the finding of remains of land mammals at several horizons in a predominantly marine section. The Etchegoin has come, therefore, in many ways to have unusual significance in the consideration of the problem of the later Tertiary of middle California.

Due to the peculiar local character of many of the Pliocene deposits of the Pacific Coast, correlation by lithology, except for very short distances, becomes extremely hazardous or impossible. For the ex-

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tension of our knowledge of the stratigraphy and palaeontology of this system it therefore becomes important to make a detailed study of the successive faunal zones in the most complete section known. Aside from the importance of finding horizons bearing vertebrate remains in the same section with those containing marine forms, it is evident that the sequence at Coalinga is the most important in middle California. The strata have been much folded, due to important diastrophic movements in post-Pliocene time. Extensive outcrops of the Pliocene south of Coalinga show exposures aggregating over ten thousand feet of strata, this being the greatest thickness of sediments belonging to this period described in America.

In the mapping of the Coalinga district by the members of the United States Geological Survey the "Jacalitos" formation was designated as a separate unit. A more extensive faunal and stratigraphic study has shown that the "Jacalitos" and the Etchegoin beds are closely linked in diastrophic history, and the former has therefore been included as a lower part of the Etchegoin in the present paper. The whole Etchegoin, contrary to the practice of many earlier geologists, is here placed in the Pliocene.

During the progress of the study of this problem the writer has frequently received the criticism and advice of Professor J. C. Merriam. The assistance derived from simultaneous study by him of the vertebrate material from Coalinga has been very valuable. Much help and encouragement both in the field and in the laboratory have been given by Dr. B. L. Clark, Instructor in Palaeontology at the University of California. The writer is indebted to Mr. R. W. Pack of the United States Geological Survey for information concerning the location of numerous excellent fossil localities in the lower Etchegoin.

PREVIOUS WORK

The Etchegoin beds of Middle California were first described in two publications by F. M. Anderson.[1] A fuller description with a summary of previous geologic and palaeontologic work was given by Ralph Arnold and Robert Anderson[2] in their report on the geology and oil resources of the Coalinga District.

[1] Anderson, F. M., A stratigraphic study of the Mount Diablo range of California, Proc. Calif. Acad. Sci., 3d ser., vol. 2, no. 1, 1905; A further study in the Mount Diablo range of California, Proc. Calif. Acad. Sci., 4th ser., vol. 3, 1908.

[2] Arnold, Ralph, and Anderson, Robert, Geology and oil resources of the Coalinga District, Fresno and Kings counties, California, U. S. Geol. Surv. Bull. 398, 1910.

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The literature dealing with the Pliocene of Middle and Northern California, but not including the Etchegoin of the Coalinga District, has recently been summarized by Bruce Martin.[3] Since the paper by Martin was written, several other publications have appeared describing the California Pliocene which will here be mentioned briefly according to date of publication.

A short paper on the Fernando group, published by W. A. English[4] in 1914, deals essentially with the Pliocene at Elsmere Creek about thirty miles northwest of Los Angeles, California, and presents faunal lists which have been found very valuable for correlation purposes in the present paper.

In the course of their investigation of the geology and economic resources of Middle California a short bulletin has been issued by R. W. Pack and W. A. English.[5] In this paper almost no palaeontologic discussion is entered into and the various horizons of upper Miocene and lower Pliocene are considered as one group, which is referred to the upper Miocene.

The Etchegoin is briefly referred to by F. M. Anderson and Bruce Martin[6] in a publication on the San Juan district, San Luis Obispo County, California, and a few species described from the Pliocene near Coalinga.

Professor J. C. Merriam[7] has recently described the occurrence of vertebrates in zones having a definite relationship to invertebrate zones north of Coalinga. The forms described from the Etchegoin occur in the area covered by the study of the writer in the present paper. Professor Merriam brings forth evidence indicating the Pliocene age of the Jacalitos and Etchegoin. In later papers Professor Merriam[8] describes a species of *Pliohippus* from the upper Etchegoin.

In a recent paper on the geology of the region bordering the west-

[3] Martin, Bruce, The Pliocene of Middle and Northern California, Univ. Calif. Publ. Bull. Dept. Geol., vol. 9, no. 15, 1916.

[4] English, Walter A., The Fernando Group near Newhall, California, Univ. Calif. Publ. Bull. Dept. Geol., vol. 8, no. 8, 1914.

[5] Pack, R. W., and English, W. A., Geology and oil prospects in Waltham, Priest, Bitterwater, and Peachtree valleys, California, U. S. Geol. Surv. Bull. 581D, 1914.

[6] Anderson, F. M., and Martin, Bruce, Neocene record in the Temblor Basin, California, and Neocene deposits of the San Juan District, San Luis Obispo County, Proc. Calif. Acad. Sci., 4th ser., vol. 4, 1914.

[7] Merriam, J. C., Tertiary vertebrate faunas of the North Coalinga Region of California, Trans. Am. Phil. Soc., vol. 22, pt. 3, 1915.

[8] Merriam, J. C., New horses from the Miocene and Pliocene of California, Univ. Calif. Publ. Bull. Dept. Geol., vol. 9, no. 4, 1915; Relationship of *Equus* to *Pliohippus* suggested by characters of a new species from the Pliocene of California, vol. 9, no. 18, 1916.

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ern side of the San Joaquin Valley Robert Anderson and R. W. Pack[9] have discussed briefly the Etchegoin and Jacalitos.

The occurrence of the invertebrate faunas in horizons with the vertebrate faunas in the type Etchegoin section north of Coalinga has been described in a short paper by the writer.[10] In this publication Arnold and Anderson's formational names Etchegoin and Jacalitos and their faunal zones in the Etchegoin were retained. In a later paper by the writer,[11] embracing a study of the hitherto little known fauna of the Jacalitos formation at the type locality, the fauna of this formation is shown to be very closely related to the overlying Etchegoin.

THE RELATION OF THE JACALITOS TO THE ETCHEGOIN

In their report on the geology and oil resources of the Coalinga district Arnold and Anderson[12] state that, "the Jacalitos is likewise conformable to all appearances with the later Miocene (Etchegoin) beds which rest above it and are largely similar in composition, the line between these two formations being drawn somewhat arbitrarily, chiefly on the basis of the fossil contents." It is, however, stated in the same publication[13] that an unconformity between the formations exists, as is shown by the overlap of the Etchegoin on the Cretaceous in the White Creek syncline, though the beds appear conformable in other parts of the district. During the study of the Pliocene of the Coalinga district by the writer the question of the relationship of the Jacalitos to the Etchegoin as defined by Arnold and Anderson has therefore been considered of especial importance.

The base of the Etchegoin as mapped by Arnold and Anderson north of Coalinga in the type section of the formation was the Glycimeris zone. It was found by the writer in attempting to extend the zones of Arnold and Anderson to the north that these tend to dis-

[9] Anderson, Robert, and Pack, R. W., Geology and oil resources of the west border of the San Joaquin Valley north of Coalinga, California, U. S. Geol. Surv. Bull. 603, 1915.

[10] Nomland, J. O., The relation of the invertebrate to the vertebrate faunal zones of the Jacalitos and Etchegoin formations of the Coalinga District, Univ. Calif. Publ. Bull. Dept. Geol., vol. 9, no. 6, 1916.

[11] Nomland, J. O., Fauna from the Lower Pliocene at Jacalitos Creek and Waltham Cañon, Fresno County, California, Univ. Calif. Publ. Bull. Dept. Geol., vol. 9, no. 14, 1916.

[12] Arnold, Ralph, and Anderson, Robert, Preliminary report on the Coalinga Oil District, California, U. S. Geol. Surv. Bull. 357, p. 41, 1908.

[13] *Ibid.*, p. 47.

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appear, and that the strata of both the Jacalitos and Etchegoin become unfossiliferous. Also on attempting to trace the Glycimeris zone southward from Coalinga it was lost within a few miles. Since no unconformity has been discovered near the base of this zone, either north or south of Coalinga or in Priest Valley, lithology and faunal evidence must be relied upon for age determination.

In large areas showing exposures of the lower Etchegoin as described by Arnold and Anderson the sandstone has a gray or a striking blue color. This has frequently been considered as being due to a coating of sand grains by vivianite. These "vivianitic" sandstones have frequently been considered characteristic of the lithology of the lower Etchegoin, and mapping has been done on that basis. As suggested by Arnold and Anderson, this horizon is not necessarily the lowest occurrence of these beds. Thus in the southern part of the Kreyenhagen Hills the strata known by their fossil contents to be of Jacalitos age are of a bluish-gray color due to "vivianite." In the Jacalitos Hills there is no change in lithology immediately below the Glycimeris zone. Some distance north of the Coalinga area as mapped by Arnold and Anderson the sandstone supposed to be characteristic of the lower Etchegoin is absent. This also holds true for beds of equivalent age in Priest Valley.

In the period in which the geological work of Arnold and Anderson was in progress the fauna of the Jacalitos was only imperfectly known. More recent study by the writer[14] has shown that the fauna of these beds is very similar to the fauna of the Etchegoin. Of the ninety-three species known from the Jacalitos at the present time a very large proportion, as shown by the accompanying table, are also found in the Etchegoin. The number in common with the Santa Margarita is shown to be small. An unconformity which occurs some distance above the Glycimeris zone has been described by the writer.[15] It is also shown that fresh-water beds occur in the lower part of the Etchegoin of Arnold and Anderson in the Kettleman Hills. These beds are believed to represent the stage of the unconformity north of Coalinga. The faunal break is not, however, greater than is to be expected in a normal succession and does not appear to mark an important separation.

[14] Nomland, J. O., Fauna of the Lower Pliocene on Jacalitos Creek and Waltham Cañon, Fresno County, California, Univ. Calif. Publ. Bull. Dept. Geol., vol. 9, no. 14, 1916.

[15] Nomland, J. O., The relation of the invertebrate to the vertebrate faunal zones of the Jacalitos and Etchegoin formations of the Coalinga District, Univ. Calif. Publ. Bull. Dept. Geol., vol. 9, no. 6, 1916.

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Thus no break has been found comparable to that assumed by Arnold and Anderson between the Etchegoin and the Jacalitos in the Coalinga region. On the contrary, the increase in the number of species and closer study of the fauna of the Jacalitos have shown a very decided similarity between the two, and that both are very different from the Santa Margarita-San Pablo. The term Jacalitos as a formational name must therefore be abandoned and, because of its close relationship to the Etchegoin, it becomes necessary to include the Jacalitos with that formation. In this paper the term lower Etchegoin will be used when referring specifically to beds equivalent to the Jacalitos, while upper Etchegoin will be used in reference to the Etchegoin as defined by Arnold and Anderson. The upper and lower Etchegoin when considered together will be called the Etchegoin group.

SUMMARY OF LIST OF "JACALITOS" OR LOWER ETCHEGOIN SPECIES

Total number of determinable species from the "Jacalitos"	93
Number of Recent species in the "Jacalitos"	37
Percentage of Recent species	40
Number of species common to the "Jacalitos" and the San Pablo-Santa Margarita	31
Number of species found in the Etchegoin (of Arnold and Anderson) or in later deposits	68
Number of species known only from the "Jacalitos"	19
Number of species found in the San Pablo, Santa Margarita, and "Jacalitos" but not known in the Etchegoin or later formations	2
Number of species found in the "Jacalitos," Etchegoin and later formations but not known in the Santa Margarita-San Pablo	37

THE ETCHEGOIN GROUP OF MIDDLE CALIFORNIA

AREAL DISTRIBUTION

Flanking the eastern foothills of the Diablo and Temblor ranges is a belt of slightly consolidated deposits which usually dip at low angles under the alluvium of the San Joaquin Valley. In the Coalinga district and some distance to the north these beds have been mapped as the Tulare, Etchegoin, and Jacalitos formations. All these now appear to be probably of Pliocene age.

In the Eastside field, comprising the northern part of the Coalinga district, the Etchegoin and the overlying Tulare as mapped by Arnold and Anderson are present. The lower, or "Jacalitos," member is without invertebrate fossils and the correlation with the type section is more difficult. South of Coalinga, in the Jacalitos Hills and in the

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Kreyenhagen Hills, the upper Etchegoin, the lower Etchegoin, and the Tulare show excellent exposures. In the Kettleman Hills only the upper Etchegoin and the Tulare are represented by outcrops.

The Etchegoin to the north of Coalinga is not so fossiliferous as it is to the south, and the lithologic characters typically developed farther south are absent. In the northern area the separation into the upper and lower Etchegoin on the basis of fossil zones becomes impossible. It also becomes exceedingly difficult to separate the Tulare from the underlying formations and from the alluvium of the valley. Judged by lithologic characters, the lower Etchegoin appears to be present at Cantua Creek. Characteristic beds presumed to be subaerial found in the vicinity of Oilfields near the base of the lower Etchegoin also seem to be present at that creek. In these deposits vertebrate material has been found. About twenty miles north of Cantua Creek the Etchegoin and the Tulare both disappear, being overlapped by the alluvium of the San Joaquin Valley.

In the mapping of the McKittrick district beds probably of the same age as those which had been separated into three formations in the Coalinga district by Arnold and Anderson were grouped by Arnold and Johnson[16] as the McKittrick formation. In portions of this district the McKittrick group is known to be represented both by the upper and lower Etchegoin and the Tulare.

Several secondary synclines are found in the Diablo Range. In many of these synclines, which usually extend in a northwest-southeast direction, are found extensive deposits of Pliocene. Among others may be mentioned Sunflower Valley, Waltham Creek-Priest Valley, White Creek Syncline, and Vallecitos Syncline.

In the White Creek Syncline the lower part of the upper Etchegoin rests unconformably on the upper Cretaceous. The basin of deposition of the upper Etchegoin evidently had a greater extent in this direction than in the lower Etchegoin, as shown by this overlap. That a more extensive movement took place in middle Etchegoin seems to be suggested by the fact that in the region near Sargent, Santa Clara County, the upper Etchegoin rests unconformably on the Franciscan and Monterey with no lower Etchegoin present. Along the upper part of Jacalitos Creek only the lower Etchegoin is found, the upper portion apparently having been removed by erosion. In the upper part of the Waltham Creek Basin are exposures of both the

[16] Arnold, Ralph, and Johnson, Harry R., Preliminary report on the McKittrick-Sunset oil region of California, U. S. Geol. Surv. Bull. 406, 1910.

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Fig. 1. Map of California Showing Important Pliocene Localities. 1. Wildcat Series at Eel River. 2. Wilson's Ranch near Santa Rosa. 3. Bolinas Bay. 4. Merced Series, type section. 5. Purisima. 6. Pescadero. 7. Año Nuevo Bay. 8. Sargent and Chittenden. 9. Lonoak. 10. Cantua Creek. 11. Priest Valley. 12. Coalinga Anticline. 13. Jacalitos Hills. 14. Kreyenhagen Hills. 15. Kettleman Hills. 16. Cholame Valley. 17. Paso Robles. 18. McKittrick. 19. Santa Maria. 20. Elsmere Cañon. 21. Santa Paula. 22. Ventura. 23. Los Angeles. 24. Puente Hills. 25. San Diego. 26. Carrizo Creek or Coyote Mountain.

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upper and lower divisions of the Etchegoin. Above the Etchegoin in that area are beds which have been correlated with the Tulare farther east. In Priest Valley the same relationship is found as in the upper part of the Waltham Creek area. The lower portion of the Etchegoin in that region is greatly faulted, so that the different faunal horizons can be traced only with difficulty. At several localities, however, fossils characteristic of the lower horizons are found. What corresponds to the Pecten coalingensis zone of the upper Etchegoin in the Jacalitos Hills can readily be distinguished in that area.

Southeast of the San Andreas fault the Etchegoin has not been extensively mapped in this region. It is known, however, to be present about one and one-half miles southeast of Lonoak. The small fauna, listed in another part of this paper, indicates a probable middle Etchegoin age. Also about thirty miles southeast of Lonoak, on Big Sandy Creek, near the southeast corner of the Priest Valley Quadrangle, an Etchegoin fauna has been obtained. In Indian Valley of the same quadrangle the Pliocene is extensively developed, resting on a considerable thickness of Santa Margarita shale. The included fauna here indicates a lower Etchegoin age. It therefore appears probable that the Etchegoin may be extensively developed along the western slope of the Diablo Range.

RELATION TO ADJOINING FORMATIONS

RELATION TO THE SANTA MARGARITA

In mapping the geology of the Coalinga district by Arnold and Anderson the base of the "Jacalitos" (lower Etchegoin) in the northern part of the region was placed at the base of a conglomerate containing a large amount of fossil wood. This horizon is about five hundred feet above the uppermost fossiliferous Santa Margarita. On being traced northward the thickness of the Santa Margarita gradually grows less and these beds finally disappear. This apparent overlapping has been taken as proof of unconformity between the "Jacalitos" and the underlying Santa Margarita. As the writer has shown in another paper,[17] there are reasons for considering that this unconformity occurs about two hundred feet lower stratigraphically than the position at which it was placed by Arnold and Anderson. The difference in the fauna between the lower Etchegoin and the Santa Margarita is such that a long time must have elapsed or a

[17] Univ. Calif. Publ. Bull. Dept. Geol., vol. 9, no. 6, 1916.

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decided change of conditions taken place between the time of deposition of the two groups of deposits. That the Santa Margarita corresponds to a part of the San Pablo farther north more closely than to the Etchegoin becomes evident from a comparison of the faunal lists in the present paper.

In the region south and west of Coalinga the Etchegoin overlies a formation decidedly different lithologically from the coarse sandstone of the Santa Margarita north of that town. This formation consists predominantly of a compact, resistant shale which has been referred questionably to the Santa Margarita. In many localities, with excellent exposures along Waltham Creek and Kreyenhagen Hills, this shale appears to grade into the overlying sandstone. As a consequence the contact line has been placed only approximately. This is shown by the work of Pack and English,[18] who state: "No evidence of unconformity between the diatomaceous shale of the Santa Margarita (?) formation and the sandy beds of the upper Miocene was found, the line of contact being drawn at the horizon where the shale becomes sandy rather than clayey and weathers yellowish brown rather than purplish." The line of demarcation is placed somewhat lower by Arnold and Anderson,[19] according to whom: "There is a non-fossiliferous transition zone of alternating sandstone and shale beds having a thickness of several hundred feet, which may belong to either formation. This has been tentatively included with the Jacalitos in mapping, the beds to which the name Santa Margarita formation is applied being restricted for the present to the underlying shale."

In the process of investigation of the Etchegoin an unconformity has been found that may mark the contact between that group and the Santa Margarita formation in the area west and southwest of Coalinga. This unconformity was first discovered at about the middle part of the southern boundary of sec. 7, T. 22 S, R. 15 E, M. D. B. & M., at an elevation of about 2100 feet. From this point it was traced in a west-northwest direction to a point at which it crosses the western boundary of the same section a little north of the middle of the southwest quarter, at an elevation of about 1600 feet. The contact continues in the same general direction until it reaches the eastern bank of Jasper Creek. No attempt was made to follow the unconformity to the southeast beyond the point of discovery. The exposures of the

[18] U. S. Geol. Surv. Bull. 581D, p. 132, 1914.

[19] U. S. Geol. Surv. Bull. 398, p. 92, 1910.

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beds in this part of the district are excellent. In some places a very sudden change was found from a fine sandy shale below to local pockets of conglomerate above the contact. At some localities the beds above contain such an abundance of shale fragments that it is in places difficult to distinguish the exact line of demarcation. The beds below could in some instances be traced to a point at which they are cut off at the contact or overlapped by the beds above. At one locality carbonaceous material was found with what apparently was the soil of the old land surface. No measurable discordance in dip or strike could be discovered.

RELATION TO THE TULARE

It is the writer's opinion that in the Coalinga and adjoining areas the Etchegoin is conformable with the Tulare, and that the two were laid down in a period of practically continuous deposition. Structurally there appears to be no break, sedimentation having continued without interruption from the Etchegoin into the Tulare. The only recorded exception to this is reported in the Priest Valley region by Pack and English,[20] who state that "in at least part of the Priest Valley region the Tulare lies unconformably upon the upper Miocene [Etchegoin] formation just described." This relationship is apparently only local, however, as in the same publication[21] it is stated that "there is no sharp change in lithology between the upper Miocene [Etchegoin] and the Tulare, and the line of contact has been drawn at the base of the beds which contain abundant pebbles of diatomaceous shale. This gradual change in lithology and the lack of any structural evidence of interrupted sedimentation suggest that the formations are conformable here." Again the same writers[22] state: "The line between the upper Miocene and the Tulare formation (Pliocene) is only a little more definite and has been drawn at the base of the beds which contain abundant pebbles of diatomaceous shale." In the McKittrick district[23] some distance south of the Coalinga area, however, the Tulare rests on the Etchegoin with angular unconformity.

The deposits of the uppermost Etchegoin were laid down under very shallow water on land conditions, as shown by the gypsiferous

[20] U. S. Geol. Surv. Bull. 581D, p. 134, 1914.

[21] *Ibid.*, p. 135.

[22] *Ibid.*, p. 133.

[23] Gester, G. C., Oral communication.

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beds and the presence of remains of land mammals in some areas. This is also shown by the character of the marine fauna, consisting of such species as *Macoma nasuta, Solen sicarius,* and *Littorina mariana.* Hence the transition would be only normal if the basin continued to be filled. The fresh-water beds with *Anodonta* and other fresh-water forms found by the writer near the base of the Etchegoin and the marine beds discovered by Arnold and Anderson in the Tulare indicate that only a slight oscillation was necessary to change from land to marine condition or the reverse during the time-interval represented by the two formations.

If towards the close of the Etchegoin there was a gradual filling up of the Etchegoin basin and fresh-water conditions finally prevailed, it is evident that this could not have taken place at all points in the district at the same time. Therefore, if the transition is gradual and not represented by unconformity, the line of separation between the two formations would represent only approximately the same period of time in such widely separated areas as Priest Valley, Kettleman Hills, and Arroyo Honda.

Thickness

As already stated, the Pliocene in the region studied is of unusual thickness. The lower Etchegoin ("Jacalitos") as measured by Arnold and Anderson at Jacalitos Creek was 3800 feet thick. This figure should be reduced somewhat, because it includes a part of the beds below the unconformity described in the present paper. This would, however, diminish the total thickness only slightly. On Canoas Creek, a few miles south of Jacalitos Creek, the upper Etchegoin measured 3600 feet. A maximum thickness of 3100 feet of Tulare, as measured by Arnold and Anderson, was found in the Kettleman Hills near the Dudley-Lemoore road. According to these measured sections, the aggregate thickness of the Pliocene south of Coalinga would be 10,500 feet. This is by far the thickest Pliocene section known in America. Heretofore the greatest thickness known has been the Merced Series, a few miles south of San Francisco, California. According to Professor A. C. Lawson,[24] the total thickness of this series is 5834 feet.

The question naturally suggests itself as to what were the possible conditions under which this great thickness of strata was deposited. The lower 6700 feet, or the Etchegoin group, is predominantly of

[24] Lawson, A. C., The post-Pliocene diastrophism of the coast of Southern California, Univ. Calif. Publ. Bull. Dept. Geol., vol. 1, p. 147, 1893.

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marine origin. On this rests with apparent conformity 3100 feet of Tulare, which is in large part of fluviatile or lacustrine origin. The lower or Etchegoin division is throughout composed of coarse sandstones, clays, and numerous beds of conglomerate with a minor proportion of tuff, coal, gypsum, and limestone. The lithology, together with the character of the invertebrate fauna and the presence of fossil remains of land mammals, gives evidence of shallow-water or terrestrial conditions throughout the Pliocene in the Coalinga region. In order to have this great thickness of strata deposited at or near shore the basin of deposition must have been sinking concomitantly with the rising of the eroded area. That this was not continuous but possibly oscillatory is indicated by the recurrence of important conglomerates at various horizons. A few miles to the west, on the other slope of the Diablo Range, Pliocene deposits are also known to be present in considerable thickness. If we assume that erosion and deposition occurred over large areas we must also consider the possibility of having available a sufficiently large land area to supply the required quantity of sediment. A question at once arises as to the possible location of an area large enough to supply by erosion during the Pliocene time sediments sufficient to form strata two miles in thickness. If we consider the present mountain ranges and the Great Valley as practically permanent structural features since Miocene time, the bringing of any material from the Sierra Nevada to be deposited in shallow water this far away seems out of question. One solution that may be offered is that the sediments were deposited only locally, and that they were derived from the stripping of frequently moving fault-blocks. On the steep sides of these blocks deposits would accumulate very rapidly and probably in considerable thickness. These sediments would, however, be only local. That such conditions existed seems to be suggested by comparison of the great thickness of strata south of Coalinga with a section about fifteen miles distant north of that town. In that area, near Oilfields, the Etchegoin is only 3000 feet in thickness. The Tulare being for the most part covered by alluvium, only small areas of it are exposed.

Definite evidence for the age of the Etchegoin was first given by Professor J. C. Merriam,[25] who has shown that fossil land mammals found at the base of the lower Etchegoin ("Jacalitos") and at several other higher horizons represent the Pliocene.

[25] Merriam, J. C., Tertiary vertebrate faunas of the North Coalinga Region of California, Trans. Am. Philos. Soc., vol. 22, pt. 3, 1915.

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It has been suggested that the Tulare may be at least in part of Pleistocene age. The Etchegoin and the Tulare have been much folded since deposition. At some localities the Tulare dips at angles of 80 degrees. This period of folding probably occurred during the time of post-Pliocene diastrophic movements described by Professor A. C. Lawson.[26] Since some or all of the folding took place in the Kettleman Hills, a region of no great relief, at least 6000 feet of strata have been removed by erosive agencies. In many localities the hills have been reduced to rounded outlines and extensive terrace deposits formed to unknown depth. As the exposures are excellent and show no evidence of faulting, it is improbable that the thickness has been overestimated in the section measured.

Structure

The dominant structural feature of the Diablo Range in the latitude of Coalinga is a broad fold plunging towards the southeast. Superimposed upon this are numerous small anticlines and synclines and in some limited areas a multitude of faults. The core of the Diablo Range consists essentially of both sedimentary and igneous rocks of the Mesozoic. The igneous rocks consist of granites and of various later basic igneous rocks of the Franciscan and later formations. The sedimentaries comprise the great thickness and variety of clastic deposits which make up the Franciscan, Knoxville, and Chico. The Tertiary rocks are found flanking the main range or as remnants folded or faulted into the older series.

Along the eastern slope of the Diablo Range are several anticlines branching away as spurs from the main fold. Of these the most important, in the region studied, is the Coalinga Anticline in the vicinity of Oilfields, about six miles north of the town of Coalinga, and its extension in the Kettleman Hills. Along the greater part of this area the Pliocene is well exposed. The structure of the Pliocene beds flanking the main range in the Kreyenhagen Hills and north of the Coalinga is in general the eastern limb of an anticline. Extending along the greater part of Jacalitos Creek, the upper part of the Waltham Creek basin, and then onwards through Priest Valley and a part of Lewis Creek is a series of small anticlines and synclines with infolded Etchegoin and Tulare. This region

[26] Lawson, A. C., The post-Pliocene diastrophism of the coast of Southern California, Univ. Calif. Publ. Bull. Dept. Geol., vol. 1, 1893; The geomorphogeny of the coast of Northern California, *ibid.*, vol. 1, no. 8, 1894.

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has also been greatly complicated by numerous faults, probably due to the same compressional forces. Many of these are extensive, causing long belts of the older rocks to appear in the midst of later formations. A large number of minor faults also are present, which are too local or too unimportant to be shown on the usual geologic map. Besides the faults in a general northwest-southeast direction there are numerous cross-faults. An interesting instance of this is found in the formation of Priest Valley by the damming of the headwaters of Lewis Creek and the consequent filling with alluvium to considerable depth. The net result of the faulting has been to give the effect of a block of Pliocene having dropped down between the older formations. In the northwestern end, a few miles northeast of Lonoak, this fault zone unites with the San Andreas fault zone, of which it appears to be a branch. At the other end it disappears in the Jacalitos syncline a few miles beyond Jacalitos Creek. In other areas of the region studied faulting since the Pliocene has been insignificant.

LITHOLOGY OF THE ETCHEGOIN

SANDSTONE, CLAY, AND CONGLOMERATE

Due largely to the complicated distribution of the older rocks in this region, from which the Pliocene is mostly a derivative, the lithology of the Etchegoin varies considerably in going from one locality to another, having in the various areas a great resemblance to the kind of rock from which the sediments were derived. Also, since the formation is largely a shallow-water deposit in more or less local basins, possibly near frequently disturbed fault zones, the lithologic character has been still further localized. In nearly all instances the beds are not clearly marked off from those adjoining, but grade into each other. Few beds can be traced on the basis of lithology for more than a short distance. In the Jacalitos Hills and Priest Valley the region has been greatly complicated by faulting.

South of Coalinga in the Kreyenhagen Hills the lower portion of the Etchegoin is composed of coarse, dark brown unfossiliferous sandstone. Interstratified with this is usually a minor proportion of yellowish-brown clay. Above this rests a great thickness of massive sandstone with prominent, highly indurated fossiliferous beds. At numerous horizons conglomerates occur or the beds may show their conglomeratic character only by occasional pebbles in the coarse sandstone. Higher up in the formation the sandstone becomes of finer

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grain and more argillaceous, with a more yellowish color. Above this, or in the lower part of the upper Etchegoin, the blue or bluish-gray so-called "vivianitic" sandstone usually first appears. These beds do not, however, appear in all parts of the district at the same time, but in some areas extend down into the lower Etchegoin. The striking blue color is particularly well shown in the Kettleman Hills. Somewhat higher up and continuing to the top the beds consist more predominantly of clays with interbedded argillaceous sandstone.

North of Coalinga the beds which have been correlated with the lower Etchegoin in the Jacalitos Hills are apparently at least in part of non-marine origin. The basal beds in this region are composed of red, brown, or gray clays. In the upper part of the lower Etchegoin the beds are more conglomeratic, consisting largely of a coarse gray sandstone with interbedded pebbles. The first invertebrate fossils appear in the lower part of the upper Etchegoin in this region. These beds are composed almost entirely of "vivianitic" sandstone with beds of conglomerate. Near the middle these grade into beds consisting of soft yellowish clays with argillaceous sands which continue to the top. This has been mapped as the San Joaquin Clays by F. M. Anderson.[27]

In Priest Valley the plane of separation of the Etchegoin from the Santa Margarita (?) below has not been definitely determined. All the lower part of the formation is nearly devoid of diagnostic fossils. These beds as a whole, up to the middle of the upper Etchegoin, are characterized, however, by a brown sandstone of medium texture with only a small proportion of conglomeratic material. Above this the deposits grade into a predominantly fine-grained shale and clay, with a large amount of interbedded coal and carbonaceous material. From here up to the top of the Etchegoin the yellowish-brown or grayish, rather coarse-grained sandstone is the most evident.

Fossils indicative of middle Etchegoin have been found on the west side of the Diablo Range near Lonoak, Monterey County, California. These fossils are imbedded in a thick series of beds composed largely of light-colored shale and volcanic ash. The rock is fine-grained, with only a very small proportion of coarse arenaceous material.

COAL AND CARBONACEOUS DEPOSITS

Carbonaceous shale and beds of coal occur at various horizons of the Etchegoin. A seam of coal was found in what apparently are

[27] Anderson, F. M., A stratigraphic study in the Mount Diablo Range of California, Proc. Calif. Acad. Sci., 3d ser., vol. 2, no. 1, 1905.

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beds of lower Etchegoin on Frame's ranch, in the upper region of Jacalitos Creek. On one of the branches at the head of Waltham Creek thin beds of carbonaceous material were found near the middle of the formation. The coal deposits in the Etchegoin of Priest Valley, however, are by far the most important both in thickness and areal extent. This area has already been mapped and lithological sections given by Robert W. Pack and Walter A. English.[28]

As indicated by these deposits, it seems possible that the Etchegoin in Priest Valley and adjacent areas may have been laid down in a basin connecting the sea in the Great Valley with that west of the Diablo Range. That such connections probably existed has already been pointed out by F. L. Ransome,[29] who states: "The Great Valley was probably occupied during the whole of the Neocene by a gulf, connecting with the ocean by one or more sounds across the Coast Ranges."

RHYOLITIC TUFFS

Effusive rocks have been found at three horizons in the Etchegoin. These consist of rather persistent tuffaceous bands interstratified with other rocks of clastic origin. From the uniform thickness of each bed, the stratification planes often being distinctly visible, and from the intimate relation to strata containing a marine fauna, it is evident that these rocks were deposited in the waters of a shallow sea. The fine, well-sorted character indicates that the volcanic action must have taken place at a considerable distance from this area, although probably in the Diablo Range, along the foothills of which the Etchegoin outcrops.

On approaching Jacalitos Creek from the Stone Cañon coal mine to the west a prominent white bed or band can be seen on the eastern bank several miles before reaching the creek. This is the lowest of the three horizons indicative of volcanic action in the Pliocene of this region. The bed is about twenty feet thick and is exposed for nearly two miles along the strike until cut off by faulting. Petrographic examination shows that quartz and orthoclase feldspar are the predominant minerals in this rock. Plagioclase feldspar is also present, but in minor proportion. The composition therefore corresponds to that of a rock usually grouped under the term rhyolitic tuff.

[28] Pack, Robert W., and English, Walter A., Geology and oil prospects in Waltham, Priest, Bitterwater, and Peachtree valleys, California, U. S. Geol. Surv. Bull. 581D, 1914.

[29] Ransome, F. L., The Great Valley of California, a criticism of the theory of isostasy, Univ. Calif. Publ. Bull. Dept. Geol., vol. 1, p. 386, 1896.

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A few miles east of the bed last described, or about five miles southeast of Coalinga, another band outcrops on the west side of the higher hills. This bed resembles very closely in texture and petrographic characters the tuffaceous material on Jacalitos Creek. These characteristics, together with faunas of middle Etchegoin age collected above and below each of the two bands, indicate that they probably belong to the same horizon.

Closing the period of deposition of the marine Etchegoin, or immediately before the transition of these beds into the prevailingly terrestrial deposits of the Tulare, volcanoes were again active in this region. This is shown by the large proportion of tuffaceous material mixed with the clays of the Mya japonica zone of the north Coalinga region. The tuffaceous material is of very fine texture and of rhyolitic composition. At one locality about one hundred feet stratigraphically below this horizon another bed of tuff has been found. This material is rather coarse-grained, as if deposited and later broken into fragments and redeposited. The tuff in this band is interstratified with a large proportion of quartz sand.

The tuffaceous beds of the upper and lower Etchegoin, being usually very persistent, should prove of value for correlation purposes if found in other parts of the field. The striking characteristics of the beds make them readily distinguishable even at a considerable distance. It appears rather remarkable that they have not been found in the Kettleman Hills and in the Kreyenhagen Hills, a few miles to the south.

GYPSUM

At several horizons of the Pliocene in this district large quantities of gypsum have been found. In no instance, however, except near the base of the Tulare formation, are these beds known to be interstratified with the clastic series. At that horizon on the eastern flank of the Kettleman Hills thick gypsiferous beds occur with extremely fossiliferous fresh-water deposits. At several horizons in the Etchegoin large quantities of gypsum are found. Since these deposits of gypsum usually are in a very fragmentary condition, they cannot be assigned definitely to an origin contemporaneous with that of the beds. It seems improbable that large quantities of gypsum occurring extensively only at definite horizons could have filtered from other sources into fissures and cavities subsequent to the deposition of the Etchegoin.

Gypsiferous beds are probably not deposited under normal marine

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conditions. It is believed, therefore, since such conditions undoubtedly frequently obtained in the Etchegoin, that the beds of gypsum were deposited, at least in part, in basins isolated from the ocean, in fresh-water lakes, or on a periodically flooded delta at the time of deposition of the Etchegoin. The climatic conditions under which this deposition took place were probably arid.

LIMESTONE

Along the divide between Jacalitos Creek and Salt Creek, about one-half mile east of Robert's ranch-house, a limestone bed outcrops. On megascopical examination the bed is found to be compact and massive in the middle, but the upper and lower portions are laminated. These laminae are very thin, being not over 2 mm. in thickness. On examination with a petrographical microscope a few minute grains of quartz were observed. The bed both above and below grades into sandstone typical of the formation. It has a thickness of about ten feet and is traceable about one-half mile until intersected by faults. With coarse sandstone above and below containing fossils indicative of a shallow marine origin, the conditions necessary for deposition of limestone in the ocean were probably not present. The conclusion is therefore reached that the limestone may have been deposited under some such conditions as might obtain in a temporary lake, or in an estuary temporarily severed from the sea.

INVERTEBRATE FAUNA

INVERTEBRATE ZONES

Four distinct faunal zones have been recognized in the Etchegoin. No fossils have been found near the base of this group. The lowest important fossiliferous horizon is the Chione elsmerensis zone, in which *C. elsmerensis* English is abundant. This faunal association extends through several hundred feet of strata in the middle portion of the lower Etchegoin and is typically that of the lower Etchegoin, or "Jacalitos," as described by Arnold and Anderson. Several of the species are unknown outside of this area. The occurrence in these beds of *C. elsmerensis* English, *C. fernandoensis* English and several other forms shows that its closest correlative is found in the lower Fernando near Newhall, Los Angeles County. The typical faunal assemblage of this zone may be found at locality 2526. Among the characteristic species may be mentioned *Astrodapsis jacalitosensis*

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Arnold, *Chione elsmerensis* English, *Chione fernandoensis* English, *Dosinia jacalitosana* Arnold, *Macoma vanvlecki* Arnold, *Paphia jacalitosana* Arnold, *Chrysodomus portolaensis* (Arnold), *Margarita johnsoni* Arnold, and *Thais kettlemanensis* Arnold.

LIST OF INVERTEBRATES FROM THE "JACALITOS" OR LOWER ETCHEGOIN, WITH OCCURRENCE AT OTHER HORIZONS

	Santa Margarita	San Pablo	"Etchegoin"	Recent
ECHINODERMATA				
Astrodapsis jacalitosensis Arnold	....	....	....	....
Astrodapsis peltoides Anderson and Martin	....	....	....	....
Astrodapsis, n. sp. A	....	....	....	....
Dendraster gibbsii (Rémond)	....	....	×	....
Dendraster gibbsii, n. var. B	....	....	×	....
Dendraster coalingensis Twitchell	....	....	×	....
PELECYPODA				
Acila castrensis (Hinds)	....	....	×	×
Arca trilineata Conrad	....	×	×	....
Cardium quadrigenarium Conrad	×	×	×	×
Chione elsmerensis English	....	....	....	....
Chione fernandoensis English	....	....	....	....
Cryptomya californica (Conrad)	?	?	×	×
Cryptomya quadrata Arnold	....	....	×	....
Cumingia californica Conrad	....	....	....	×
Cyrena californica Gabb	....	×	....	....
Diplodonta parilis (Conrad)	....	×	×	....
Dosinia jacalitosana Arnold	....	....	....	....
Glycimeris coalingensis Arnold	....	×	×	....
Glycimeris septentrionalis (Middendorf)	....	×	×	×
Leda, cf. tephria Dall	....	....	....	×
Macoma baltica (Linné)	....	....	....	×
Macoma jacalitosana Arnold	....	....	....	....
Macoma nasuta (Conrad)	×	×	×	×
Macoma secta (Conrad)	×	×	×	×
Macoma vanvlecki Arnold	....	....	....	....
Metis alta (Conrad)	×	×	....	×
Modiolus rectus Conrad	×	×	×	×
Monia macroschisma (Deshayes)	....	....	....	×
Mulinia densata Conrad	×	×	×	....
Mytilus coalingensis Arnold	?	?	×	....
Mytilus kewi Nomland	×	....	....	....
Ostrea atwoodi Gabb	....	×	×	....
Pandora punctata Conrad	....	....	×	×
Panope generosa (Gould)	×	×	×	×

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LIST OF INVERTEBRATES FROM THE "JACALITOS" OR LOWER ETCHEGOIN—(*Continued*)

	Santa Margarita	San Pablo	"Etchegoin"	Recent
Paphia jacalitosensis Arnold	....	....	....	....
Paphia staminea (Conrad)	×	×	?	×
Paphia tenerrima (Carpenter)	....	....	×	×
Pecten etchegoini wattsi Arnold	....	....	×	....
Pecten (Hinnites) giganteus (Gray)	×	....	×	×
Pecten healeyi Arnold	....	....	×	....
Pecten oweni Arnold	....	....	×	....
Pecten terminus Arnold	....	....	×	....
Periploma argentaria Conrad	....	....	....	×
Phacoides annulatus (Reeve)	×	×	×	×
Phacoides richthofeni (Gabb)	×	×	....	×
Psamobia edentula (Gabb)	....	....	....	×
Sanguinolaria nuttalli Conrad	....	×	....	×
Saxidomus nuttalli Conrad	×	×	×	×
Schizothaerus nuttalli Conrad	×	×	×	×
Semele, sp.	....	....	....	....
Siliqua lucida (Conrad)	....	×	....	×
Solen sicarius Gould	....	....	×	×
Spisula albaria (Conrad)	×	×	×	....
Spisula coalingensis (Arnold)	....	....	×	....
Spisula hemphilli (Dall)	....	....	....	×
Tellina bodegensis Hinds	....	....	....	×
Thracia jacalitosensis Arnold	....	....	....	....
Tivela trigonalis Nomland	....	....	×	....
Yoldia cooperi Gabb	×	×	....	×
Zirphaea crispata (Linné)	....	....	....	×
GASTROPODA				
Astralium arnoldi Nomland	....	....	....	....
Calliostoma coalingensis Arnold	....	....	×	....
Calliostoma kerri Arnold	....	....	×	....
Calyptraea filosa (Gabb)	×	×	×	....
Cancellaria fernandoensis tribulis, n. var.	....	....	....	....
Cancellaria crassa, n. sp.	....	....	....	....
Chrysodomus coalingensis Nomland	....	....	....	....
Chrysodomus imperialis Dall	....	?	×	....
Chrysodomus packardi, n. sp.	....	....	....	....
Chrysodomus portolaensis (Arnold)	....	....	×	....
Crepidula adunca Sowerby	....	×	....	×
Crepidula princeps Conrad	×	×	×	....
Ficus nodiferous Gabb	×	×	×	....
Fissuridea subelliptica Nomland	....	....	....	....
Margarita johnsoni Arnold	....	....	×	....
Murex concinna, n. sp.	....	....	....	....

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LIST OF INVERTEBRATES FROM THE "JACALITOS" OR LOWER ETCHEGOIN—(*Concluded*)

	Santa Margarita	San Pablo	"Etchegoin"	Recent
Murex perangulatus Nomland	....	....	....	....
Murex tethys, n. sp.	....	....	....	....
Nassa californiana (Conrad)	....	....	×	×
Natica orbicularis Nomland	....	....	×	....
Natica recluziana Petit	×	×	×	×
Olivella biplicata Sowerby	....	....	×	×
Purpura turris Nomland	....	....	×	....
Sinum scopulosum (Conrad)	×	×	×	....
Thais kettlemanensis Arnold	....	....	×	....
Thais lamellosa (Gmelin)	....	....	×	×
Trophon belcheri avitum, n. var.	....	....	....	....
Trophon coalingense Arnold	....	....	×	....
Trophon magister Nomland	....	....	×	....
Turris carpenteriana (Gabb)	....	....	....	×
Turris coalingensis (Arnold)	....	....	×	....
Turris tryoniana (Gabb)	....	....	....	×
Turritella nova Nomland	....	....	....	....
CIRRIPEDIA				
Balanus concavus Bronn	....	....	×	×
Tamiosoma gregaria Conrad	×	....	×	....

At a number of localities in the Jacalitos Hills and Kreyenhagen Hills in beds of the lower middle Etchegoin a faunal assemblage has been found characterized by several species unknown at other horizons of the formation. This fauna, known as the Turritella nova zone, is found typically developed at locality 2533. At this station the fauna consists of very large specimens of *Pecten oweni* Arnold, *Pecten terminus* Arnold, and *Phacoides annulatus* (Reeve). Well-preserved specimens of *P. terminus* may be found which have the very unusual width of 145 mm. Associated with these species are numerous gastropods such as *Ficus nodiferous* Gabb, *Turris carpenteriana* (Gabb), *Turris tryoniana* (Gabb), and *Turritella nova* Nomland.

The most easily recognizable by its faunal assemblage and the most persistent in areal extent in the Etchegoin is the Pecten coalingensis zone. The name was first applied by Arnold to a zone occurring in the Kettleman Hills and in the Jacalitos Hills about 800 feet below the summit of the formation. Subsequent work by the writer has shown that this faunal association, occurring at approximately

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the same horizon, is also found well developed in the Priest Valley, and that it is present north of Coalinga in beds traceable to the type section of the Etchegoin of Arnold and Anderson. At all localities where this association is found the stratigraphic range of the fauna appears very short, and there is no repetition at other horizons of a similar assemblage. A strikingly large number of the species are unknown outside this zone. In it are found a coral, a brachiopod, several species of *Pecten* unknown in other horizons. One of the most characteristic forms is *Pecten etchegoini* Anderson and its varieties *nutteri* Arnold and *wattsi* Arnold. It has been found that this species, which has been used largely for correlation in the Pliocene, has a very long range. This form occurs south of Coalinga from below the Turritella nova zone to the uppermost beds of the Etchegoin group, or approximately through 4000 feet of strata. *Trophon magister* Nomland, formerly thought of very limited range, has been found in this zone. A number of the more recent forms are also rarely found, such as *Pecten hastatus,* var. *hindsii* Carpenter, *Murex festivus* Hinds, *Trophon gracilis* (Perry).

Uppermost in the predominantly marine deposits of the Etchegoin and directly below the fresh-water deposits of the Tulare a faunal assemblage is found which has been named by Ralph Arnold the Mya japonica zone. It is found persistently in the Kettleman Hills and in the Kreyenhagen Hills. North of Coalinga a similar fauna has been found in a resistant band of argillaceous tuff in the outermost foothills. In Priest Valley the zone does not occur and the line of demarcation between the Etchegoin and the Tulare is distinguished with difficulty. The fauna of the uppermost part of this zone is mainly that of shallow-water or littoral conditions. A number of species found immediately below the typical Mya japonica zone at several localities are included with the fauna of that zone in the accompanying list. The only species of this zone unknown in other horizons is *Littorina mariana* Arnold and its variety *L. mariana,* var. *alta* Arnold. In most of the localities along this zone the so-called fish bulbs are found in large numbers. North of Coalinga the extinct horse *Pliohippus proversus* Merriam is found at this horizon.

ETCHEGOIN FAUNA WEST OF THE DIABLO RANGE

It has already been stated that the Pliocene is present on the west side of the Diablo Range in the latitude of Coalinga. The following Pliocene species have been obtained on the north bank of Whalen

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Creek a short distance above its junction with Stone Cañon and on Big Sandy Creek about one-half mile above its confluence with Stone Cañon, near the southeast corner of Priest Valley Quadrangle.

FAUNA FROM BIG SANDY CREEK AND WHALEN CREEK

Dendraster gibbsii (Rémond)	Pecten healeyi Arnold
Cardium, cf. quadrigenarium Conrad	Phacoides, sp.
Cryptomya californica (Conrad)	Schizothaerus nuttalli (Conrad)
Macoma nasuta (Conrad)	Siliqua lucida (Conrad)
Mulinia densata Conrad	Solen, cf. sicarius Gould
Ostrea, sp.	Zirphaea, sp.
Pandora punctata Conrad	Calliostoma, sp.
Paphia, sp.	Chrysodomus, sp.
Paphia, cf. tenerrima (Carpenter)	Nassa californiana (Conrad)
Pecten estrellanus catalinae Arnold	Natica recluziana Petit

About one and one-half miles southwest of Lonoak post-office, Priest Valley Quadrangle, the following fauna indicative of the middle Etchegoin has been found. The fossils occur in a series of beds of fine white ashy shale, extensively distributed in this area.

FAUNA FROM LONOAK

Cryptomya californica (Conrad)	Fissuridea, cf. unica, n. sp.
Ostrea atwoodi Gabb	Natica, sp.
Pecten oweni Arnold	Trophon, sp.
Pecten estrellanus Conrad, var.	Tamiosoma gregaria Conrad

Also on Vineyard Creek, San Luis Obispo County, and Indian Valley, Monterey County, west of the Diablo Range, Etchegoin sandstone and conglomerate overlying Santa Margarita shale is extensively distributed. The included fauna is apparently of lower Etchegoin or "Jacalitos" age.

FAUNA OF LACUSTRINE(?) BEDS

In the north central part of the Kettleman Hills, near the middle of the southern part of sec. 12, T. 22 S, R. 17 E, M. D. B. & M., a bed containing fresh-water fossils was discovered recently by the writer. According to its location with respect to the upper Mulinia zone as mapped by Arnold and Anderson this bed comes only a short distance above what is called by them the base of the Etchegoin. This would therefore come at about the same horizon as is represented by the unconformity recently described[30] in the region north of Coalinga. It appears that the time-interval marked by the unconformity of

[30] Nomland, J. O., Relation of the invertebrate to the vertebrate faunal zones of the Jacalitos and Etchegoin in the North Coalinga Region, California, Univ. Calif. Publ. Bull. Dept. Geol., vol. 9, p. 80, 1916.

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the northern area is indicated by fresh-water deposits in the Kettleman Hills. Although fossils are very abundant in this bed, only the following forms could be identified: *Anodonta nitida,* n. sp., *Goniobasis,* sp.

RANGE OF TEMPERATURE AND DEPTH

As shown by Ralph Arnold, the temperature of the ocean during Etchegoin time was probably somewhat warmer than that of the Pacific Ocean in the latitude of Coalinga at the present time. A large number of the Etchegoin forms, with other species indicative of decidedly warmer water, at present live from Monterey to San Diego. The large specimens of *Pecten terminus* Arnold are indicative of warm conditions. *Metis alta* (Conrad) and *Periploma argentaria* Conrad found in the lower Etchegoin indicate warm water. No cold-water phases have been recognized.

The invertebrate fauna of the Etchegoin is composed entirely of forms living in shallow water. At some horizons, locally, forms characteristic of brackish or even fresh water are present. Species characteristic of considerable depth have not been found.

SERPULA(?) REEF

In beds of middle Etchegoin in the Kreyenhagen Hills, on the south bank of Garza Creek, sec. 35, a reef outcrops which is made up almost entirely of tests of the genus *Serpula(?).* This reef is exposed along the hillside for about thirty yards, with a thickness of about one and one-half feet.

COMPARATIVE TABLE SHOWING STRATIGRAPHIC RELATIONSHIP OF FAUNAL ZONES SOUTH OF COALINGA

Arnold, 1910 Faunal zones	Nomland, 1916 Faunal zones	Arnold, 1910 Formation	Nomland, 1916 Formation
Mya	Mya		
Pecten coalingensis	Pecten coalingensis	Etchegoin	
Upper Mulinia			
Glycimeris or Lower Mulinia	Turritella nova	**Unconformity**	Etchegoin
Middle			
Big Trophon		Jacalitos	
	Chione elsmerensis		
			Unconformity
		Unconformity (?)	Santa Margarita
		Santa Margarita (?)	

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Vertebrate Fauna

Perhaps the most interesting and valuable material for purposes of correlation found in the Etchegoin is represented by the remains of land mammals occurring at many widely separated localities. This material has been found at several horizons in both the upper and lower divisions of this group.

The most important of these occurrences is about ten miles northeast of Coalinga. In that area in both the upper and lower Etchegoin vertebrates are found in zones with invertebrate zones or alternating with them. The vertebrates from this area have already been described by Professor J. C. Merriam.[31] A description of the zonal distribution and the occurrence of the invertebrates and vertebrates accompanied by faunal lists has been given in another paper by the writer.[32]

A short distance north of Cantua Creek remains of fossil land mammals have also been found. These occur in highly colored, possibly land-laid beds which probably correspond to the lower Etchegoin near Oilfields. The whole Etchegoin in this area is without invertebrate fossils, so that the age determination must be based on the vertebrate fossils, lithology, and tracing the beds into those of known age to the south. The fauna found in this region is comprised essentially of the teeth of *Pliohippus coalingensis* (Merriam), found also in the middle Etchegoin near Oilfields.

South of Coalinga vertebrate material has been found in the Etchegoin in the Kreyenhagen Hills and in the Kettleman Hills. The so-called bulbous fish growths are found at several horizons in both the lower and upper Etchegoin in the Kreyenhagen Hills. Besides numerous fragments of marine vertebrates from various zones of the formation, a camel tooth has been found at locality 2991 with a large invertebrate fauna of the Pecten coalingensis zone. In the Kettleman Hills numerous bulbous fish growths have been found at several horizons of the upper Etchegoin. A fossil beaver tooth has been described by Miss Louise Kellogg[33] from this area. Fragments of a fossil horse have also been reported from the northern end of the Kettleman Hills.

[31] Merriam, J. C., Tertiary vertebrate faunas of the North Coalinga Region of California, Trans. Am. Philos. Soc., vol. 22, pt. 3, 1915.

[32] Nomland, J. O., The relation of the invertebrate to the vertebrate faunal zones of the Jacalitos and Etchegoin Formations of the Coalinga District, California, Univ. Calif. Publ. Bull. Dept. Geol., vol. 9, no. 6, 1916.

[33] Kellogg, Louise, A fossil beaver from the Kettleman Hills, California, Univ. Calif. Publ. Bull. Dept. Geol., vol. 6, no. 17, 1911.

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FAUNAL LIST OF THE ETCHEGOIN OF THE COALINGA DISTRICT

	Chione elsmerensis zone	Turritella nova zone	Pecten coalingensis zone	Mya japonica zone	Lower Fernando	Lower Sargent	Upper Sargent	Purisima	Lower Merced	Recent
ANTHOZOA										
Astrangia coalingensis Vaughan	....	....	UC	....	....	....	....	....	....	....
ECHINODERMATA										
Astrodapsis jacalitosensis Arnold	UC	....	....	....	....	....	....	....	....	....
Astrodapsis peltoides Anderson and Martin	UC	....	....	....	....	....	....	....	....	....
Astrodapsis, sp. A	....	....	....	....	....	....	....	....	....	....
Dendraster arnoldi Twitchell	....	....	UC	....	....	....	....	....	....	....
Dendraster coalingensis Twitchell	....	....	....	....	....	....	....	....	....	....
Dendraster gibbsii (Rémond)	C	C	C	R	....	×	....	×	....	....
Dendraster perrini (Weaver)	....	....	C	....	....	....	....	×	....	....
Dendraster, sp. A	....	....	....	....	....	....	....	....	....	....
Dendraster, sp. B	....	....	....	....	....	....	....	....	....	....
Sismondia arnoldi Twitchell	....	....	....	....	....	....	....	....	....	....
Sismondia coalingensis Twitchell	....	....	....	....	....	....	....	....	....	....
VERMES										
Serpula (?)	....	....	....	....	....	....	....	....	....	....
BRYOZOA										
Several species	....	....	....	....	....	....	....	....	....	....
BRACHIOPODA										
Terebratalia occidentalis Dall	....	....	....	R	....	....	....	....	....	....
Terebratalia smithi Arnold	C	....	....	....	×	....	....	....	....	....
PELECYPODA										
Acila castrensis (Hinds)	....	....	....	R	×	....	×	×	....	×
Anodonta nitida, n. sp.	....	....	....	....	....	....	....	....	....	....
Arca trilineata Conrad	C	C	C	C	×	×	×	×	×	....
Cardium corbis (Martyn)	C	....	....	....	....	....	....	....	....	×
Cardium quadrigenarium Conrad	....	....	R	....	×	....	....	....	×	×
Chama pellucida Sowerby	....	....	C	....	....	....	....	....	....	×
Chione elsmerensis English	C	....	....	....	×	....	....	....	....	....
Chione fernandoensis English	C	....	....	....	×	....	....	....	....	....
Cryptomya californica (Conrad)	C	....	C	C	×	....	×	×	×	×
Cryptomya quadrata Arnold	C	?	....	....	....	×	×	....	....	....
Cumingia californica Conrad	....	....	....	....	....	....	....	....	....	×
Cyrena californica Gabb	....	....	....	....	....	....	....	....	....	....
Diplodonta harfordi Anderson	....	....	....	....	....	....	....	....	....	....

(C indicates that the species is common; R indicates that the species is rare; U indicates that the species is unknown outside of this horizon; × indicates other formations in which the species is found.)

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FAUNAL LIST OF THE ETCHEGOIN OF THE COALINGA DISTRICT—(*Continued*)

	Chione elamerensis zone	Turritella nova zone	Pecten coalingensis zone	Mya japonica zone	Lower Fernando	Lower Sargent	Upper Sargent	Purisima	Lower Merced	Recent
Diplodonta parilis (Conrad)	C	....	C	....	....	....	....	....	....	....
Dosinia jacalitosana Arnold	C	....	....	....	×	....	....	....	....	....
Glycimeris coalingensis Arnold	C	....	C	....	....	×	....	....	....	....
Glycimeris septentrionalis (Middendorf)	....	....	....	....	....	....	....	....	....	×
Leda, cf. taphria Dall	....	....	....	....	....	....	....	....	....	....
Macoma baltica (Linné)	....	....	....	....	....	....	....	....	....	×
Macoma inquinata (Deshayes)	C	C	C	C	....	×	....	×	×	×
Macoma inquinata affinis, n. var.	....	....	....	C	....	....	....	....	....	....
Macoma jacalitosana Arnold	UR	....	....	....	....	....	....	....	....	....
Macoma nasuta (Conrad)	C	....	C	....	×	×	×	×	×	×
Macoma secta (Conrad)	....	....	....	....	×	×	....	....	....	×
Macoma vanvlecki Arnold	C	....	....	....	....	....	....	....	....	....
Metis alta (Conrad)	C	....	....	....	×	....	....	....	....	×
Modiolus fornicatus Carpenter	....	....	R	....	....	....	....	....	....	×
Modiolus rectus Conrad	C	C	C	R	....	....	....	×	....	×
Monia macroschisma (Deshayes)	C	C	....	....	....	....	....	....	....	×
Mulinia densata Conrad	C	....	C	....	....	....	....	....	....	....
Mya japonica Jay	....	....	....	C	....	×	....	....	....	×
Mytilus coalingensis Arnold	....	?	C	....	×	×	....	....	....	....
Mytilus kewi Nomland	....	....	....	....	....	....	....	....	....	....
Ostrea atwoodi Gabb	C	C	C	....	....	×	....	....	....	....
Ostrea lurida Carpenter	....	....	C	C	....	....	....	....	....	×
Ostrea vespertina Conrad	....	....	C	C	....	....	....	....	....	....
Ostrea vespertina, var. sequens Arnold	....	....	C	C	....	....	....	....	....	....
Pandora punctata Conrad	....	?	....	....	....	....	×	×	....	×
Panope generosa (Gould)	C	C	C	....	×	×	×	×	....	×
Paphia jacalitosana Arnold	UR	....	....	....	....	....	....	....	....	....
Paphia staleyi (Gabb)	....	....	....	....	....	×	×	×	×	....
Paphia staminea (Conrad)	C	C	....	....	....	×	×	....	×	×
Paphia tenerrima (Carpenter)	C	....	....	....	×	....	×	×	×	×
Pecten coalingensis Arnold	....	....	UC	....	....	....	....	....	....	....
Pecten egregius, n. sp.	....	....	UR	....	....	....	....	....	....	....
Pecten etchegoini Anderson	....	....	C	....	....	×	....	....	....	....
Pecten etchegoini nutteri Arnold	....	....	C	....	....	×	....	....	....	....
Pecten etchegoini wattsi Arnold	....	....	C	R	....	×	×	....	×	....
Pecten (Hinnites) giganteus (Gray)	....	....	....	....	....	....	....	....	....	×
Pecten hastatus hindsii Carpenter	....	....	R	....	....	....	....	....	....	×
Pecten healeyi Arnold	....	....	....	....	×	....	....	×	....	....
Pecten oweni Arnold	C	C	....	....	×	×	....	×	....	....
Pecten proteus, n. sp.	....	....	UC	....	....	....	....	....	....	....
Pecten terminus Arnold	C	C	....	....	....	....	....	....	....	....

(C indicates that the species is common; R indicates that the species is rare; U indicates that the species is unknown outside of this horizon; × indicates other formations in which the species is found.)

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FAUNAL LIST OF THE ETCHEGOIN OF THE COALINGA DISTRICT—(*Continued*)

	Chione elsmerensis zone	Turritella nova zone	Pecten coalingensis zone	Mya japonica zone	Lower Fernando	Lower Sargent	Upper Sargent	Purisima	Lower Merced	Recent
Periploma argentaria Conrad	....	....	....	....	....	....	....	....	....	×
Petricola carditoides (Conrad)	....	....	R	....	....	....	....	....	....	×
Phacoides annulatus (Reeve)	....	C	....	....	×	×	....	×	×	×
Phacoides richthofeni (Gabb)	R	....	....	....	....	....	....	....	....	×
Phacoides sanctaecrusis Arnold	....	....	....	....	×	....	....	....	....	....
Pholadidea ovoidea Gould	....	....	....	....	....	....	....	....	....	×
Placunanomia californica Arnold	....	....	....	....	....	....	....	....	....	....
Psamobia edentula (Gabb)	....	....	....	....	×	....	....	....	....	×
Psephis lordi (Baird)	....	....	....	....	....	....	....	....	....	....
Sanguinolaria nuttalli Conrad	....	....	R	....	....	....	....	....	....	×
Saxidomus nuttalli Conrad	....	C	C	....	....	×	....	....	....	×
Schizothaerus nuttalli Conrad	C	C	....	....	....	×	×	×	×	×
Semele fausta, n. sp.	....	....	UR	....	....	....	....	....	....	....
Semele rubropicta Dall	....	....	R	....	....	....	×	....	....	×
Siliqua lucida (Conrad)	C	C	....	....	....	....	....	....	....	×
Solen sicarius Gould	C	....	....	C	×	×	×	×	×	×
Spisula albaria (Conrad)	....	....	....	....	....	×	×	×	×	....
Spisula coalingensis (Arnold)	....	....	....	....	....	....	×	....	....	....
Spisula falcata (Gould)	....	....	....	....	....	....	....	....	....	×
Spisula hemphilli (Dall)	C	....	....	....	....	....	....	×	....	×
Tellina bodegensis Hinds	C	....	....	....	....	....	....	....	×	×
Tivela trigonalis Nomland	....	....	....	....	....	....	....	....	....	....
Thracia formosa, n. sp.	....	....	R	....	....	....	....	....	....	....
Thracia jacalitosana Arnold	....	....	....	....	....	....	....	....	....	....
Transennella californica Arnold	....	....	....	....	....	....	×	....	....	....
Yoldia cooperi Gabb	....	....	....	....	×	×	....	×	....	×
Zirphaea crispata (Linné)	....	....	....	....	....	....	....	....	....	×
GASTROPODA										
Astralium arnoldi Nomland	....	....	....	....	....	....	....	....	....	....
Calliostoma coalingensis Arnold	C	C	C	....	....	....	....	....	....	....
Calliostoma etchegoinensis Nomland	....	....	....	....	....	....	....	....	....	....
Calliostoma kerri Arnold	....	....	C	....	....	....	....	....	....	....
Calyptraea filosa (Gabb)	C	C	C	C	×	×	×	×	×	....
Cancellaria crassa, n. sp.	....	UR	....	....	....	....	....	....	....	....
Cancellaria fernandoensis tribulis, n. var.	....	....	....	....	....	....	....	....	....	....
Cancellaria rapa, n. sp.	....	....	....	....	....	....	....	....	....	....
Cancellaria tritonidea Gabb	....	....	R	....	×	....	×	....	....	....
Chrysodomus coalingensis Nomland	....	....	....	....	....	....	....	....	....	....
Chrysodomus imperialis Dall	R	....	....	....	....	....	....	....	....	....

(C indicates that the species is common; R indicates that the species is rare; U indicates that the species is unknown outside of this horizon; × indicates other formations in which the species is found.)

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FAUNAL LIST OF THE ETCHEGOIN OF THE COALINGA DISTRICT—(*Continued*)

	Chione elsmeresis zone	Turritella nova zone	Pecten coalingensis zone	Mya japonica zone	Lower Fernando	Lower Sargent	Upper Sargent	Purisima	Lower Merced	Recent
Chrysodomus packardi, n. sp.	....	....	....	....	....	....	....	....	....	....
Chrysodomus portolaensis (Arnold)	C	C	....	....	....	×	....	×	×	....
Columbella (Astyris) richthofeni Gabb	....	....	....	....	....	....	×	×	×	×
Crepidula adunca Sowerby	....	R	....	....	....	....	....	....	....	....
Crepidula princeps Conrad	C	....	C	C	×	×	×	×	....	....
Drillia mercedensis Martin	....	....	....	....	....	....	....	×	×	....
Epitonium varicostata Stearns	....	....	C	....	....	....	....	....	....	....
Ficus nodiferous Gabb	C	C	....	....	×	....	....	....	....	....
Fissuridea subelliptica Nomland	....	UR	....	....	....	....	....	....	....	....
Fissuridea unica, n. sp.	....	....	UC	....	....	....	....	....	....	....
Goniobasis kettlemanensis Arnold	....	....	R	....	....	....	....	....	....	....
Littorina mariana Arnold	....	....	....	UC	....	....	....	....	....	....
Littorina mariana alta Arnold	....	....	....	UC	....	....	....	....	....	....
Margarita johnsoni Arnold	C	?	....	....	....	....	....	....	....	....
Murex concinna, n. sp.	....	....	....	....	....	....	....	....	....	....
Murex festivus Hinds	....	....	R	....	....	....	....	....	....	×
Murex perangulatus Nomland	....	....	....	....	....	....	....	....	....	....
Murex tethys, n. sp.	....	C	R	....	....	....	....	....	....	....
Nassa californiana (Conrad)	C	C	C	....	....	....	....	×	....	×
Natica convexa Nomland	....	....	....	....	....	....	....	....	....	....
Natica orbicularis Nomland	C	C	R	....	....	×	×	×	×	....
Natica recluziana Petit	C	C	C	C	×	×	....	....	....	×
Natica recluziana alta Dall	....	....	....	....	....	....	×	....	×	×
Olivella biplicata Sowerby	....	....	C	....	....	....	×	....	×	×
Olivella pedroana (Conrad)	....	....	....	....	....	....	×	×	×	×
Pisania fortis angulata Arnold	....	....	....	....	×	....	....	....	×	....
Purpura turris Nomland	....	....	....	....	....	....	....	....	....	....
Sinum scopulosum (Conrad)	....	?	....	....	×	....	....	....	....	....
Tegula (Chlorostoma) pulcella, n. sp.	....	....	UR	....	....	....	....	....	....	....
Thais kettlemanensis Arnold	C	C	....	....	....	×	....	....	....	....
Thais lamellosa (Gmelin)	C	C	C	C	....	....	×	×	×	×
Trophon belcheri avitum, n. var.	....	UR	....	....	....	....	....	....	....	....
Trophon coalingense Arnold	R	?	?	....	....	....	....	....	....	....
Trophon gracilis (Perry)	....	....	R	....	....	....	....	....	....	×
Trophon magister Nomland	C	C	R	....	....	....	....	....	....	....
Turris carpenteriana (Gabb)	....	C	....	....	....	....	....	×	....	×
Turris carpenteriana fernandoana Arnold	....	....	R	....	×	....	....	....	....	×
Turris coalingensis (Arnold)	R	C	....	....	×	....	....	....	....	....
Turris tryoniana (Gabb)	....	C	....	....	....	....	....	....	....	×
Turritella nova Nomland	....	UC	....	....	....	....	....	....	....	....
Turritella vanvlecki Arnold	....	....	....	....	....	....	....	....	....	....

(C indicates that the species is common; R indicates that the species is rare; U indicates that the species is unknown outside of this horizon; × indicates other formations in which the species is found.)

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FAUNAL LIST OF THE ETCHEGOIN OF THE COALINGA DISTRICT—(*Concluded*)

	Chione elsmerensis zone	Turritella nova zone	Pecten coalingensis zone	Mya japonica zone	Lower Fernando	Lower Sargent	Upper Sargent	Purisima	Lower Merced	Recent
CRUSTACEA										
Balanus concavus Bronn	....	C	C	....	....	....	....	....	....	×
Cancer fissus Rathbun	....	....	....	....	....	....	....	....	....	....
Loxorhynchus grandis Stimpson	....	....	....	....	....	....	....	....	....	....
Tamiosoma gregaria Conrad	C	?	....	....	....	...	....	....	....	....
PISCES										
Carcharodon arnoldi Jordan	....	....	....	....	....	....	....	....	....	....
Fish, bulbous growths	....	....	....	....	....	....	....	....	....	....
REPTILIA										
Testudo(?), sp.	....	....	....	....	....	....	....	....	....	....
MAMMALIA										
Camelops or Pliauchenia, sp.	....	....	....	....	....	....	....	....	....	....
Castor californicus Kellogg	....	....	....	....	....	....	....	....	....	....
Cervus or Odocoileus, sp.	....	....	....	....	....	....	....	....	....	....
Mastodon	....	....	....	....	....	....	....	....	....	....
Neohipparion molle Merriam	....	....	....	....	....	....	....	....	....	....
Pliohippus coalingensis (Merriam)	....	....	....	....	....	....	....	....	....	....
Pliohippus proversus Merriam	....	....	....	....	....	....	....	....	....	....
Pliohippus, cf. tejonensis (Merriam)	....	....	....	....	....	....	....	....	....	....
Procamelus(?), sp.	....	....	....	....	....	....	....	....	....	....
Tayassu or Mylohyus	....	....	....	....	....	....	....	....	....	....

(C indicates that the species is common; R indicates that the species is rare; U indicates that the species is unknown outside of this horizon; × indicates other formations in which the species is found.)

SUMMARY OF ETCHEGOIN INVERTEBRATE FAUNAL LIST

Anthozoa	1
Echinodermata	11
Brachiopoda	2
Pelecypoda	80
Gastropoda	53
Crustacea	4
Total number of determinable Etchegoin invertebrate species	149
Number of Recent molluscan species in the Etchegoin	50
Percentage of Recent molluscan species	39
Percentage of Recent species in gastropod fauna of Etchegoin	21
Number of species known only from the Etchegoin of Coalinga	42
Total number of species reported from the lower Fernando near Newhall	60
Number of species common to the Etchegoin and the lower Fernando near Newhall	27
Total number of species reported from the lower Pliocene near Sargent	38
Number of species common to the Etchegoin and the lower Pliocene beds near Sargent	30

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Total number of species reported from the upper Pliocene near Sargent	45
Number of species common to the Etchegoin and the upper Pliocene beds near Sargent	26
Total number of species reported from the Purisima	59
Number of species common to the Etchegoin and Purisima	32
Total number of species reported from the lower Merced	41
Number of species common to the Etchegoin and lower Merced	25

Age and Correlation of the Etchegoin

History of Correlation

The name Etchegoin Beds, used by F. M. Anderson[34] in the first descriptions of the formation, included only the upper Etchegoin as used by the writer. These beds were thought by Anderson to be of approximately the same age as the San Pablo formation, this correlation being based chiefly on lithology. The Etchegoin Beds and the San Pablo were both included in the Pliocene. The thick series of strata immediately underlying the Etchegoin Beds, including the Jacalitos, Santa Margarita and a portion of the Vaqueros as later mapped by Ralph Arnold and Robert Anderson, were grouped by F. M. Anderson as the Coalinga Beds. These beds were believed to be of upper Miocene age and to be separated from the Etchegoin Beds by an unconformity.

The Jacalitos and Etchegoin formations as mapped by Arnold and Anderson[35] were held to represent the middle and upper Miocene. The Etchegoin was considered equivalent to a considerable part of the San Pablo. The Etchegoin was also believed to be equivalent to, or possibly older than, the Purisima and was thought to be earlier than the Merced.

According to Professor J. P. Smith,[36] "The lower division of the upper Miocene consists of the San Pablo-Santa Margarita-Jacalitos faunas, which are a unit, or nearly so . . . the Jacalitos being merely the upper division of the Santa Margarita, and both together being

[34] Anderson, F. M., A stratigraphic study in the Mount Diablo Range of California, Proc. Calif. Acad. Sci., 3d ser., vol. 2, no. 1, 1905; A further study in the Mount Diablo Range of California, Proc. Calif. Acad. Sci., 4th ser., vol. 3, 1908.

[35] Arnold, Ralph, and Anderson, Robert, Preliminary report on the Coalinga Oil District, U. S. Geol. Surv. Bull. 357, 1908; Arnold, Ralph, Palaeontology of the Coalinga District, Fresno and Kings counties, California, U. S. Geol. Surv. Bull. 396, 1909; Arnold, Ralph, and Anderson, Robert, Geology and oil resources of the Coalinga District, California, U. S. Geol. Surv. Bull. 398, 1910.

[36] Smith, J. P., Geologic range of Miocene invertebrate fossils of California, Proc. Calif. Acad. Sci., 4th ser., vol. 3, pp. 161–182, 1912.

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the approximate equivalent of the San Pablo." The Etchegoin as recognized by Arnold and Anderson was placed in the upper Miocene. The Purisima was believed to be higher than the Etchegoin and of Pliocene age.

In a short paper by W. A. English[37] on the Fernando near Newhall, Los Angeles County, California, the conclusion was arrived at that the lower Fernando probably does not differ greatly in age from the Etchegoin of Arnold and Anderson.

In a recent paper by R. W. Pack and W. A. English[38] on the region west of the Coalinga district little attempt was made at a faunal study of the Etchegoin. The Jacalitos and Etchegoin were grouped as upper Miocene. According to these writers, "the Jacalitos and Etchegoin formations are believed to be in the main younger than the true Santa Margarita, although the fauna contained in the lower part of what is mapped as upper Miocene in Waltham Cañon shows a close similarity to that of the true Santa Margarita."

The Jacalitos and Etchegoin are grouped by Robert Anderson and R. W. Pack[39] as upper Miocene, or possibly in part lower Pliocene, and are thought to be of the same age as the San Pablo.

By finding remains of land mammals with the marine deposits in the Etchegoin it becomes possible to correlate this group definitely also with distant terrestrial deposits containing only remains of land vertebrates. The mammalian remains have been studied by Professor J. C. Merriam,[40] who places both the Etchegoin and Jacalitos of Arnold and Anderson in the Pliocene. The Santa Margarita-San Pablo is placed in the upper Miocene.

The study of the San Pablo of middle California by Dr. B. L. Clark apparently shows that this group is of upper Miocene age. The Santa Margarita is considered by him equivalent to the upper part of the San Pablo, while the Etchegoin is recognized as Pliocene. Dr. Clark states that it is his opinion that the Jacalitos is probably younger than the San Pablo.

In a recent publication on the Pliocene of California by Bruce

[37] English, W. A., The Fernando Group near Newhall, California, Univ. Calif. Publ. Bull. Dept. Geol., vol. 8, no. 8, 1914.

[38] Pack, R. W., and English, W. A., Geology and oil prospects in Waltham, Priest, Bitterwater, and Peachtree valleys, California, U. S. Geol. Surv. Bull. 581D, 1914.

[39] Anderson, Robert, and Pack, R. W., Geology and oil resources of the west border of the San Joaquin Valley north of Coalinga, California, U. S. Geol. Surv. Bull. 603, 1915.

[40] Merriam, J. C., Tertiary vertebrate faunas of the North Coalinga Region of California, Trans. Am. Philos. Soc., vol. 22, pt. 3, 1915.

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Martin[41] the lower Pliocene beds found near Sargent, called San Pablo by Jones, are referred to the same horizon as the Etchegoin. Martin also states that a portion of the Purisima is probably equivalent to a portion of the Etchegoin of Arnold and Anderson.

AGE DETERMINATION

As will be seen by a comparison of the faunal lists, the lower Etchegoin has a greater percentage of Recent species than the upper division or than the formation as a whole. According to the usual custom of calculating by the Lyell percentage method, the lower Etchegoin should therefore be placed later in the geologic time-scale than the upper Etchegoin. In this instance we know by undoubted stratigraphic evidence that this is not a fact. We know also that during the deposition of approximately 7000 feet of Pliocene a considerable faunal evolution must have occurred.

That the percentage method has only a very limited degree of accuracy was shown by Dr. W. H. Dall[42] nearly twenty-five years ago in the following statements:

> There is no doubt that Lyell's hypothesis has been of great use in settling early Neozoic nomenclature, and has generally hitherto been applied in a manner to which little exception could be taken. But the old conception of the mathematical individuality of species has passed away, never to return, and the numerical estimates based upon it are no longer practicable in the absence of any method of determining the personal equation of different palaeontologists in their estimates of what constitutes a species.
>
> The classification retaining these names is no longer numerical, but stratigraphic and developmental, and the formations classified under a given name are, for the writer at least, not necessarily synchronous, except where stratigraphically continuous, or synchronic only in a very wide and general sense.
>
> It is believed that American geologists are well agreed that the minor subdivisions of the systems cannot in America at present be subjected to any rigid parallelism with the minor subdivisions of other lands, and that the difficulty of correlation increases with the differences of latitude and distance. Concurring in this opinion, theoretically and practically, no attempt at such correlation has been attempted by the writer within the geological limits assigned to him.

It appears, therefore, that the Lyell percentage method can be applied only to the larger divisions and only in a very general way. The very fine distinctions which have frequently been made as to the relative age of many of the California Tertiary formations based on

[41] Martin, Bruce, The Pliocene of Middle and Northern California, Univ. Calif. Publ. Bull. Dept. Geol., vol. 9, no. 15, 1916.

[42] Dall, W. H., Correlation papers, Neocene, U. S. Geol. Surv. Bull. 84, p. 179, 1892.

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the percentage method are of little value. The finer age determinations will probably have to be made by comparing highly specialized forms from the various horizons and by a direct comparison with faunal zones, the position of which has already been found in a section of known stratigraphic sequence.

In regard to the Pliocene beds of Florida Dr. Dall[43] states:

> In the discussion of these tables, if we adopt the old-fashioned method, it appears that, throwing all doubtful species into the category of extinct forms, we have from the Waccamaw beds 125 out of 180 species still living, or about 70 per cent; while from the Crotan beds we have 80 out of 96 species represented in the recent fauna, or over 83 per cent. By this method the Pliocene character of the beds is obvious, according to the numerical rule.

Also for the Miocene of Maryland the same writer[44] shows that the number of Recent species ranges from 8.5 to 20 per cent. It will thus be seen that the percentage of Recent species in the Etchegoin, 39+ per cent, falls between these two series of figures.

The Etchegoin of the Coalinga district rests unconformably on the Santa Margarita, which, as shown by Dr. B. L. Clark,[45] is probably of the same age as the upper part of the San Pablo. The percentage of Recent species in the San Pablo is 23+. According to Dr. Clark, this would place the San Pablo in the upper Miocene or possibly lower Pliocene.

In regard to the mammalian remains found in the Etchegoin Professor J. C. Merriam[46] states: "The time-relations of the Jacalitos [lower Etchegoin] vertebrates to the faunas of the Great Basin Province are not entirely clear, but the closest relationships seem to be with the lower Pliocene."

CORRELATION WITH OTHER PLIOCENE FORMATIONS

On comparison of the Etchegoin in the region studied by the writer with other Pliocene faunas of California it is found that at no other locality do we find a section that corresponds to the whole Etchegoin studied at Coalinga.

The fauna most closely related to the lower Etchegoin is found in the lower Fernando near Newhall, Los Angeles County. Of the sixty

[43] Dall, W. H., Tertiary mollusks of Florida, Trans. Wagner Inst. Sci., vol. 3, pt. 2, p. 215, 1892.

[44] Dall, W. H., The relations of the Miocene of Maryland to that of other regions and to the Recent fauna, Md. Geol. Surv., Miocene, p. 147, 1904.

[45] Clark, B. L., Fauna of the San Pablo Group of Middle California, Univ. Calif. Publ. Bull. Dept. Geol., vol. 8, no. 22, 1915.

[46] Merriam, J. C., Tertiary vertebrate faunas of the North Coalinga Region, Trans. Am. Philos. Soc., vol. 22, pt. 3, p. 30, 1915.

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species listed from that locality, twenty-six are also found in the Etchegoin of Coalinga. Considering the distance by which these localities are separated, a striking resemblance is evident. Among the species strongly suggesting this close relationship may be mentioned *Terebratalia smithi* Arnold, *Pecten healeyi* Arnold, *Pecten oweni* Arnold. With these forms occur also several species unknown except from the lower Fernando near Newhall and from the Etchegoin near Coalinga; these are *Chione elsmerensis* English, *Chione fernandoensis* English, *Turris coalingensis* Arnold, and *Dosinia jacalitosana* Arnold. Good specimens of *Pecten estrellanus catalinae* Arnold, listed by Arnold from the lower Fernando near Newhall, have been obtained by the writer from beds that appear to represent middle Etchegoin at Big Sandy Creek on the west side of the Diablo Range.

The fauna most closely related to the upper Etchegoin is undoubtedly that listed from the lower Pliocene beds at Sargent. Of the thirty-eight species listed from that formation at Sargent, thirty are found in the upper Etchegoin at Coalinga. The species in common include *Dendraster gibbsii* (Rémond), *Pecten etchegoini* Anderson and its varieties *nutteri* Arnold and *wattsi* Arnold.

As will be seen by the Etchegoin fauna as summarized in this paper, nearly one-half of the species reported from the Purisima and more than one-half of the species reported from the lower Merced are found in the Etchegoin near Coalinga. The characteristic species common to the Merced, and especially those common to the Purisima, seem to be such as are confined to the middle and upper Etchegoin. It seems probable, however, that the Etchegoin and Merced basins represent different faunal provinces. In the Merced are included several species indicating a closer relationship to the northern forms than the warm water Etchegoin fauna.

Summary

1. The accumulation of over 10,000 feet of Pliocene has occurred under shallow marine or terrestrial conditions.

2. In the period in which this accumulation took place the floor of the basin of deposition was several times raised locally above sea-level. After the prevailingly terrestrial conditions had begun marine deposition occurred for brief periods.

3. Diastrophic movements of great magnitude occurred in post-Pliocene time in the Coalinga region.

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4. The strata above the Santa Margarita and below the Tulare belong to one period of deposition.

5. The Santa Margarita-San Pablo fauna is distinctly different from that of the Etchegoin.

6. As shown by both invertebrates and the vertebrates, the whole Etchegoin is of Pliocene age.

7. An unconformity occurring in the lower portion of what has been mapped as the Etchegoin southeast of Coalinga is probably the line of division of the Etchegoin from the underlying Santa Margarita.

8. An unconformity occurring in the Etchegoin north of Coalinga above the "Glycimeris zone" is probably of only local importance.

9. Four distinct faunal zones have been recognized in the Etchegoin.

10. The lower Etchegoin is most closely related to the lower Fernando near Newhall, while the upper Etchegoin is most closely related to the lower part of the Pliocene beds at Sargent.

DESCRIPTION OF ETCHEGOIN INVERTEBRATE LOCALITIES

Out of about two hundred fossil localities in the Etchegoin near Coalinga and in the adjoining regions the following have been selected as showing typically the faunal association of the Etchegoin.

All townships and ranges referred to Mount Diablo Base Line and Meridian.

2089. Middle of eastern boundary of NW ¼ of NW ¼ Sec. 19, T. 19 S, R. 16 E. Mya zone, uppermost Etchegoin.

2091. On west slope of 1100-foot hill near NE corner of NW ¼ Sec. 26, T. 19 S, R. 15 E. Vertebrate and invertebrate locality, lowest invertebrate fossiliferous zone.

2093. In creek bed immediately east of 900-foot hill, SE corner of NW ¼ of NW ¼ Sec. 13, T. 19 S, R. 15 E. Lowest invertebrate fossiliferous zone, type section of the formation as used by Arnold and Anderson.

2096. Near middle of eastern boundary of SW ¼ of SE ¼ Sec. 35, T. 19 S, R. 15 E. In this area the lowest invertebrate fossilferous zone.

2104. Middle of northern boundary of NE ¼ Sec. 12, T. 21 S, R. 14 E. Upper Etchegoin.

2110. Middle of southern boundary of Sec. 1, T. 21 S, R. 14 E. Upper middle Etchegoin.

2376. Middle of southern boundary of SE ¼ of SW ¼ Sec. 6, T. 20 S, R. 16 E. Pecten coalingensis zone.

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2377. Center of NW ¼ of SE ¼ Sec. 34, T. 19 S, R. 15 E. Lowest invertebrate fossiliferous zone.

2520. Near center of SE ¼ of NW ¼ Sec. 24, T. 21 S, R. 14 E. About 200 yards east of Alcalde-Jacalitos Ranch road. Chione elsmerensis zone.

2523. Center of SE ¼ of SE ¼ Sec. 27, T. 21 S, R. 14 E. Short distance west of most southern curve of Alcalde-Jacalitos Ranch road around Curry Mountain, about 15 yards above road. Probably Turritella nova zone.

2526. At junction of Jacalitos Creek and Jasper Creek, near SW corner of Sec. 6, T. 22 S, R. 15 E. Chione elsmerensis zone. One of typical "Jacalitos" localities.

2532. Near top of small ridge on old Coalinga-Stone Cañon road, SE corner of NW ¼ of NW ¼ Sec. 21, T. 21 S, R. 14 E. Chione elsmerensis zone.

2533. Middle of southern boundary of NW ¼ of NE ¼ Sec. 29, T. 21 S, R. 14 E, on north bank of Waltham Creek. Turritella nova zone.

2534. About 100 yards south of B. M. 1699, on old Coalinga-Stone Cañon road, near middle of western boundary of Sec. 31, T. 21 S, R. 14 E. Chione elsmerensis zone.

2535. About 20 yards stratigraphically above 2534.

2616. Near SW corner of NW ¼ of SE ¼ Sec. 3, T. 22 S, R. 14 E. Probably Chione elsmerensis zone.

2619. On divide at SE corner of NE ¼ of SE ¼ Sec. 32, T. 21 S, R. 14 E. Lower middle Etchegoin.

2622. About 20 yards SE of B. M. 1699, Sec. 31, T. 21 S, R. 14 E. Chione elsmerensis zone.

2643. South middle part of NE ¼ of NW ¼ Sec. 29, T. 21 S, R. 14 E. Chione elsmerensis zone.

2649. Near center of NW ¼ of SE ¼ Sec. 19, T. 21 S, R. 14 E. Middle Etchegoin.

2650. At NE corner of SW ¼ of SE ¼ Sec. 19, T. 21 S, R. 14 E. Middle Etchegoin.

2663. East central part of NE ¼ of NW ¼ Sec. 34, T. 21 S, R. 14 E. Probably Chione elsmerensis zone.

2664. In saddle of ridge, NE corner of NW ¼ Sec. 34, T. 21 S, R. 14 E. Turritella nova zone.

2669. SW corner of SE ¼ of NW ¼ Sec. 34, T. 21 S, R. 14 E. Undifferentiated Etchegoin.

2670. On south side of 1600-foot hill near north central part of SW ¼ of NW ¼ Sec. 34, T. 21, R. 14 E. About middle Etchegoin.

2672. Near center of SE ¼ of NW ¼ Sec. 34, T. 21 S, R. 14 E. Chione elsmerensis zone.

2679. Middle of northern boundary of SE ¼ of NE ¼ Sec. 7, T. 22 S, R. 15 E. Resistant strata containing *Astrodapsis* in abundance. Chione elsmerensis zone.

2680. On ridge, south central part of NW ¼ of NW ¼ Sec. 8, T. 22 S, R. 15 E. Turritella nova zone.

2684. Near middle of SE ¼ of NE ¼ Sec. 12, T. 22 S, R. 14 E. Undifferentiated lower Etchegoin.

2693. On ridge extending from 1910-foot hill near NE corner of SW ¼ of NE ¼ Sec. 24, T. 21 S, R. 14 E. Lower middle Etchegoin.

2958. Middle of eastern boundary of NE ¼ of NE ¼ Sec. 7, T. 23 S, R. 17 E. Immediately below lowest "vivianitic" sandstone. Turritella nova zone.

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2962. Near SE corner of NW ¼ Sec. 7, T. 23 S, R. 17 E. Hard stratum on bank of creek. Chione elsmerensis zone.
2964. NE corner of NW ¼ Sec. 7, T. 23 S, R. 17 E. Probably Turritella nova zone.
2965. SE corner of NE ¼ Sec. 36, T. 22 S, R. 16 E. Immediately north of road. Mya japonica zone.
2966. Near SW corner of NE ¼ Sec. 35, T. 22 S, R. 16 E. Upper middle Etchegoin.
2971. Near center of SW ¼ Sec. 9, T. 23 S, R. 17 E. Probably Turritella nova zone
2973. At SE corner of Sec. 8, T. 23 S, R. 17 E. On small branch of creek. Lowest fossiliferous zone in this region.
2974. South central part of SE ¼ of SW ¼ Sec. 8, T. 22 S, R. 16 E. On small creek. Pecten coalingensis zone.
2975. About 100 feet above 2974. Pecten coalingensis zone.
2976. Near NE corner of NW ¼ Sec. 24, T. 22 S, R. 15 E, at elevation of about 1500 feet. Chione elsmerensis zone.
2977. South central part of SW ¼ Sec. 13, T. 22 S, R. 15 E. Middle Etchegoin.
2982. Sec. 8, T. 22 S, R. 16 E. On ridge east of Zapato Creek, about ¼ mile SE of Adolph Kreyenhagen's home. Pecten coalingensis zone.
2985. Near SW corner of SE ¼ Sec. 20, T. 22 S, R. 16 E. Middle Etchegoin.
2986. About 50 feet stratigraphically higher than 2985.
2987. West central part of Sec. 20, T. 22 S, R. 16 E. Middle Etchegoin.
2988. About 50 yards SE of 2987, about same horizon.
2991. Near center of SE ¼ Sec. 17, T. 22 S, R. 16 E. On top of ridge south of road. Pecten coalingensis zone.
3001. On bank of creek near center of NW ¼ of NW ¼ Sec. 14, T. 20 S, R. 12 E. Pecten coalingensis zone.
3003. On bank of creek near SW corner of Sec. 10, T. 20 S, R. 12 E. Pecten coalengensis zone.
3004. West central portion of Sec. 10, T. 20 S, R. 12 E. Hard stratum on creek bank, short distance above coal.
3005. At confluence of two small creeks near center of NE ¼ of NE ¼ Sec. 9, T. 20 S, R. 12 E. A few hundred feet below coal. Middle Etchegoin.
3007. Immediately above pipe line near center of SW ¼ of NW ¼ Sec. 26, T. 20 S, R. 12 E. Middle Etchegoin.
3010. Near central portion of Sec. 35, T. 20 S, R. 12 E. Middle Etchegoin.
3011. About 600 yards south of 3010. Probably Chione elsmerensis zone.
3013. On creek near NE corner of SW ¼ of NE ¼ Sec. 23, T. 20 S, R. 12 E. Probably float from middle Etchegoin.
3016. SE corner of NE ¼ of NE ¼ Sec. 14, T. 20 S, R. 12 E, on bank of creek. Middle Etchegoin.
3020. On small branch of creek, near SE corner of Sec. 27, T. 20 S, R. 12 E. Middle Etchegoin.

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ANTHO

Astrangia coalingensis

ECHINODE

Astrodapsis jacalitosens

Astrodapsis peltoides A

Astrodapsis, sp. A .....

Dendraster arnoldi Tw

Dendraster coalingensi

Dendraster gibbsii (R

Dendraster perrini (W

Dendraster, sp. A .....

Dendraster, sp. B .....

Sismondia arnoldi Twi

Sismondia coalingensis

BRACHIO

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DESCRIPTION OF SPECIES

ANODONTA NITIDA, n. sp.

Plate 9, figure 2

Type specimen no. 11091, Univ. Calif. Coll. Invert. Palae.

Shell of moderate size, equivalve, thin, rather compressed, ventral part of sides of posterior end flattened, with subpentagonal, angular outline. Beaks low, inconspicuous. Anterior region about one-fourth of length of shell; anterior dorsal margin rounded, with slightly increased convexity a short distance in front of beaks; anterior extremity rather sharply angular; posterior extremity slightly truncated; posterior dorsal margin to upper angle of truncation nearly two-thirds of distance from beak to posterior end; from this angle to lower angle of truncation margin is slightly concave; posterior ventral margin has increased convexity slightly more than one-third of length of shell from posterior end. Surface ornamented by numerous wide concentric ridges. Height, 38 mm.; length, 54 mm.

This species may be recognized by compressed form, inconspicuous anteriorly located beaks, angular outline, and flattened posterior ventral portion of sides.

Occurrence.—At locality 2999, on ridge a little east of middle of southern boundary of sec. 12, T. 22 S, R. 17 E, M. D. B. & M., northern end of Kettleman Hills. At the type locality this species occurs with *Goniobasis,* sp., in fresh-water horizon at or near the base of the upper Etchegoin.

PECTEN EGREGIUS, n. sp.

Plate 6, figures 3, 3*a*, 3*b*

Type specimen no. 11090, Univ. Calif. Coll. Invert. Palae.

Shell equilateral, equivalve, thin, rather compressed; with smooth, regularly rounded base. Dorsal margins long; umbonal angle about 70 degrees. Right valve with about 22–23 moderately strong, rounded ribs; in each interspace there is one small, often invisible, rounded riblet; anterior ear long, arcuate in front, ornamented above byssal notch by about six distinct, radiating ridges and numerous incremental lines; byssal notch well defined; posterior ear very small, sculptured by low radiating ridges and inconspicuous incremental lines. Left valve with about 22 subequal ribs, which are not so prominent as those of the right valve, but with auxiliary riblets more distinct; anterior ear large, with sculpture consisting of faint incremental lines and about twelve radiating ridges; posterior ear similar to that on the

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right valve. Dimensions of type, which is a rather small specimen: height, 31 mm.; width, 24 mm.; width of hinge, 13 mm.

Occurrence.—At localities 2991, 2975, Pecten coalingensis zone, upper Etchegoin Pliocene.

PECTEN PROTEUS, n. sp.

Plate 6, figures 2, 2*a*, 2*b*, 2*c*

Type specimen no. 11089, Univ. Calif. Coll. Invert. Palae.

Pecten deserti Conrad. Arnold, Ralph, U. S. Geol. Surv. Bull. 396, p. 76, pl. 26, figs. 3, 4, 1909.

Pecten deserti Conrad. Arnold, Ralph, and Anderson, Robert, U. S. Geol. Surv. Bull. 398, pl. 48, figs. 3, 4, 1910.

Shell thin, equilateral, equivalve, compressed, with smooth regularly convex margins. Dorsal margins slightly concave; apical angle about 95 degrees. Right valve ornamented externally by 21–24 wide, moderately high, rounded ribs; on each side of major ribs is usually a faint auxiliary riblet; interspaces between major ribs less than width of ribs; anterior ear slightly longer than posterior, sculptured by about five low radial ridges and indistinct incremental lines; posterior ear ornamented with about seven low, radial ridges and nearly invisible incremental lines. Left valve in general similar to right, but has higher, more strongly rounded, major ribs with narrow interspaces; anterior ear with about seven radiating lines. Dimensions of rather small left valve of type: height, 37 mm.; width, 33 mm.; width of hinge line, 17 mm.

Specimens of this species found in the Coalinga region have heretofore been identified as *Pecten deserti* Conrad. On comparison of *P. deserti* from the type locality at Carrizo Mountain, San Diego County, with *P. proteus,* n. sp., several marked differences may be observed. In *P. deserti* the ribs are higher, flatter above, with more nearly vertical sides; on the left valve the ribbing continues without interruption from ears over the outer depressed dorsal margins, while in *P. proteus,* n. sp., the corresponding areas have no ribs. The ears of *P. deserti* are larger, more strongly curved, and have less depression where ears join dorsal margins of shell; also the dorsal margins show less marked concavity. These instances can be better recognized by seeing the comparative figures shown in this paper.

Occurrence.—At localities 2991, 2975, with a large fauna characteristic of the Pecten coalingensis zone, upper Etchegoin.

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MACOMA INQUINATA AFFINIS, n. var.

Plate 9, figures 1, 1*a*, 1*b*

Type specimen, no. 11092, Univ. Calif. Coll. Invert. Palae.

Shell large, equivalve, short, trapezoidal, with rather long ligamental groove. Sides moderately convex, slightly excavated a little below anterior dorsal margin, giving a flange-like appearance, with depressed area on both valves extending from umbones to posterior dorsal margin. Beaks low, adjacent, a little anterior to middle. Anterior margin evenly rounded, with increased convexity at anterior extremity; posterior dorsal margin arcuate, with greater curvature behind ligamental groove; posterior ventral margin concave where intersected by depression extending from beak, on most specimens base more strongly curved a little posterior to middle. Surface covered by numerous, unequal, concentric lines. Dimensions: height, 52 mm.; length, 64 mm.

This species may be distinguished from the typical *Macoma inquinata* (Deshayes) by its larger size, the flange immediately anterior to the beaks, depressed area extending from umbones to posterior ventral margin, rather long ligamental groove, and increased convexity near middle of base.

Occurrence.—Locality 2965, Mya japonica zone, uppermost Etchegoin.

SEMELE FAUSTA, n. sp.

Plate 9, figures 3, 3*a*, 3*b*

Type specimen no. 11102, Univ. Calif. Coll. Invert. Palae.

Shell small, inequilateral, with moderately convex valves and low beaks. Posterior end much shorter than anterior; anterior dorsal margin straight, with evenly rounded anterior end; posterior dorsal margin slightly convex, with posterior end truncated inwards. Surface sculptured by numerous, about equidistant, low, concentric lines; with a nearly obsolete fold extending from the beaks to the posterior end. Resilifer weak, narrow; ligamental groove almost obsolete. Right valve with long, rather low laterals; anterior cardinal indistinct, posterior cardinal low and slender; left valve with feeble laterals and indistinct, thin cardinals. Dimensions: length, 35 mm.; height, 30 mm.

This form is of the same general type as *Semele rubropicta* Dall, from which it may be distinguished by its having a greater length in proportion to the width, the anterior portion being longer, the fold

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more nearly obsolete, and by the long, straight, anterior dorsal margin. The hinge also differs in having the weak, narrow resilifer and long, narrow laterals, this being especially true of the anterior teeth.

Occurrence.—At locality 2991, upper Etchegoin, on Zapato Creek, Fresno County; at the type locality this species occurs with *Thracia formosa,* n. sp., *Fissuridea unica,* n. sp., *Tegula (Chlorostoma) pulcella,* n. sp., and the associated fauna.

THRACIA FORMOSA, n. sp.

Plate 9, figures 4, 4*a*

Type specimen no. 11103, Univ. Calif. Coll. Invert. Palae.

Shell small, inequilateral, thin, moderately compressed. Beaks low, about three-fifths length of shell from anterior end. Posterior dorsal margin slightly convex; posterior end truncated. Junction of anterior dorsal and ventral margins marked by slight increase in convexity. Ventral margin evenly arcuate. Surface ornamented by distinct, uniform, rounded, concentric ridges; with a well developed, broad sulcation extending from the beak to the posterior extremity. Hinge weak; right valve with small, rather thick tooth projecting at angle of nearly 45 degrees to plane of shell. Dimensions: height, 27 mm.; width, 19 mm.

Occurrence.—At locality 2991, with a large fauna characteristic of the upper Etchegoin.

FISSURIDEA UNICA, n. sp.

Plate 11, figures 3, 3*a*, 3*b*

Type specimen no. 11100, Univ. Calif. Coll. Invert. Palae.

Shell subovate, conical, elevated, straight to slightly convex sides, with apex a little anterior. Ornamented by numerous prominent, rounded, rather thin, radiating ridges with narrow interspaces. Incremental lines unequal, often more prominent than the radiating ridges. Apical orifice oblong, anterior to the apex, bounded inside by a posteriorly truncated callus. Dimensions of type, which is a rather small specimen: height, 14 mm.; maximum diameter, 25 mm.; minimum diameter, 19 mm.

This species can readily be recognized by its height, ovate base, and radial ribbing with narrow interspaces.

Occurrence.—In the upper Etchegoin, with a large fauna of the Pecten coalingensis zone at locality 2991.

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TEGULA (CHLOROSTOMA) PULCELLA, n. sp.

Plate 12, figures 3, 3*a*

Type specimen no. 11101, Univ. Calif. Coll. Invert. Palae.

Shell conical, thin, with about six whorls; suture distinct, appressed. Sides of whorls flat, giving an almost uniform slope from apex to base. Surface striated by faint, oblique, incremental lines and numerous low, rounded, axial riblets; on the sides of the whorls near the base are about three fine spiral threads. Base of body-whorl flattish, with sharp angle at periphery; ornamented by incremental lines and two or three nearly obsolete spirals around umbilical area. Aperture subquadrate, with thin outer lip; inner lip with two small tubercles, of which the lower is almost invisible. Umbilicus open; outer edge of umbilical area limited by a distinct, sharp ridge. Height, 23 mm.; diameter of slightly deformed type, 26 mm.

This species is easily recognized by its flat sides, conical form, and low axial ornamentation.

Occurrence.—At locality 2991, with a large fauna of the Pecten coalingensis zone, upper Etchegoin.

CHRYSODOMUS PACKARDI, n. sp.

Plate 12, figures 4, 4*a*, 4*b*

Type specimen no. 11096, Univ. Calif. Coll. Invert. Palae.

Shell thick, has about four or five rapidly increasing whorls, with distinct, appressed suture. Whorls slightly convex, tabulate, almost channeled above. Surface of whorls ornamented by coarse, square, spiral ribs, between which are fine thread-like intercalaries and narrow interspaces; on body-whorl and continuing nearly to lower end of canal there are about nine and on the whorls of spire three of these major spirals. Crossing the whorls, and especially evident on spire, are numerous longitudinal ribs; on body-whorl of some specimens these ribs become nearly obsolete; where spirals cross the axial ribs a reticulate appearance is produced. Aperture rectangular, forming a short, wide canal; with thin, sharp, outer lip; inner lip incrusted, smooth. Dimensions of type: diameter, 17 mm.; height unknown.

Occurrence.—At localities 2958, 2985, middle Etchegoin. At the type locality near middle of western boundary of NW ¼ of NW ¼ sec. 8, T. 23 S, R. 17 E, M. D. B. & M., this species occurs with the following species: *Arca trilineata* Conrad, *Calliostoma,* cf. *kerri* Ar-

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nold, *Calyptraea filosa* (Gabb), *Dendraster,* sp., *Macoma,* cf. *inquinata* (Deshayes), *Nassa californiana* (Conrad), *Ostrea atwoodi* Gabb, *Paphia staminea* (Carpenter), *Thais kettlemansis* Arnold, *Trophon,* sp., *Turritella,* cf. *nova* Nomland.

MUREX (OCINEBRA) CONCINNA, n. sp.

Plate 12, figures 6, 6*a*

Type specimen no. 11093, Univ. Calif. Coll. Invert. Palae.

Shell small, subfusiform, with rather low spire. Whorls four or more, increasing rapidly in size. Body-whorl with distinct angles at shoulder and base, giving the sides a flattened appearance. Each whorl with about nine wide, prominent, axial ribs; on body-whorl these extend from suture down to about middle of canal. The spiral ornamentation on the body-whorl consists of about eight and on the spire two, high, rounded cords which become fainter on canal; between these, especially on upper part, are fine thread-like intercalaries; where the spirals intersect the axial ribs a decidedly nodose appearance is produced. Aperture oblong-elliptical; outer lip thickened, terminating in a long, narrow, recurved canal; inner lip slightly incrusted; columella faintly marked by spiral sculpture. Dimensions: height, 25 mm.; maximum diameter, about 13 mm.

Occurrence.—At localities 2643, 2985, middle Etchegoin.

MUREX (OCINEBRA) TETHYS, n. sp.

Plate 12, figures 2, 2*a*, 2*b*

Type specimen no. 11099, Univ. Calif. Coll. Invert. Palae.

Shell small, heavy; whorls four or five; suture distinct, slightly channeled; apex acute; body-whorl large and ventricose. Whorls sculptured by prominent, coarse spiral cords and low, often almost invisible, intercalaries; the body-whorl has about seven and the spire two of the major cords; these are crossed by eight high, angular, longitudinal ribs which disappear on lower part of body-whorl; where these cross the spirals the shell becomes slightly nodose, this being especially evident on upper part of whorls, where a rather sharp shoulder is produced. Aperture wide, elliptical, with thick outer lip; inner lip apparently smooth, incrusted; canal short, slightly curved. Dimensions of type: height, 21 mm.; diameter, 15 mm.

Apparently this form most closely resembles *Ocinebra lurida,* var. *cerritensis* Arnold, from which it may be distinguished by its higher

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and more acute spire, the presence of small spiral intercalaries, and the sharper angle at shoulder of whorls.

Occurrence.—At localities 2986, 2985, 2988, 2643; middle Etchegoin.

TROPHON BELCHERI AVITUM, n. var.

Plate 11, figure 5

Type specimen no. 11094, Univ. Calif. Coll. Invert. Palae.

Shell large, heavy, with five or more whorls; spire moderately elevated; suture appressed. Whorls angulate at shoulder, with prominent angle at lower part of body-whorl; immediately below this is a deep groove which varies considerably in size in different specimens and in front of which the lower part of body-whorl protrudes. Whorls and canal ornamented by about eleven raised axial folds or varices which at the shoulder become sharp spines, also at lower angle of body-whorl where intersected by varices the shell usually becomes nodose. Outer lip thin, canal slightly recurved. Height of type, 66 mm.; diameter of body-whorl, 60 mm.

This species differs from *Trophon belcheri* Hinds by shorter and stouter nodes at shoulder, rather prominent nodes near base of body-whorl, shorter columella, and lower spire than most specimens of *T. belcheri*. From *T. magister* Nomland it differs in having a larger number of varices, in being more spinose at shoulder, and by more evident development of nodes on lower part of body-whorl.

An interesting problem in evolution could probably be solved by a study of the large Trophons having the characteristic groove immediately below the body-whorl. In the lower Miocene this type first appears as *T. gabbianum* Anderson; in the upper Miocene it takes the form of *T. carisaensis* Anderson; in the Pliocene we find *T. magister* Nomland, while the Recent form is *T. belcheri* Hinds.

Occurrence.—At locality 2988, middle Etchegoin.

CANCELLARIA CRASSA, n. sp.

Plate 12, figures 7, 7*a*

Type specimen no. 11098, Univ. Calif. Coll. Invert. Palae.

Shell slender, solid, with about five whorls; suture distinct, impressed. Whorls sharply angulated a little less than one-third of the distance below suture, somewhat tabulate above; near the base of the body-whorl is another distinct angle, giving the periphery of whorls

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a flattened appearance. Axially sculptured by eleven prominent ribs which become less marked on the tabulate portion above, on the body-whorl these extend only to lower peripheral angle. Spiral sculpture on the body-whorl consists of seven and on the spire five strongly elevated cords. Outer lip of type defective. Aperture narrow, with long twisted canal. Inner lip slightly incrusted, pillar long and slender, with two thin, sharp plaits on the lower part. Height, about 41 mm.; diameter, 20 mm.

Occurrence.—At locality 2533, near middle of southern boundary of NW ¼ of NE ¼, sec. 29, T. 21 S, R. 14 E, M. D. B. & M., on north bank of Waltham Creek. At the type locality this form occurs with the following characteristic Etchegoin species: *Macoma vanvlecki* Arnold, *Pecten terminus* Arnold, *Pecten oweni* Arnold, *Phacoides annulatus* (Reeve), *Bathytoma tryoniana* (Gabb), *Ficus nodiferous* Gabb, *Turris coalingensis* (Arnold), *Thais kettlemanensis* Arnold, *Turritella nova* Nomland.

CANCELLARIA FERNANDOENSIS TRIBULIS, n. var.

Plate 12, figures 1, 1*a*

Type specimen no. 11095, Univ. Calif. Coll. Invert. Palae.

Shell broadly fusiform, spire high, with about four whorls; body-whorl large; suture distinct, almost channeled. Whorls with sharp angle immediately below suture, giving a tabulate appearance to the upper part; sculptured with about sixteen prominent axial ribs, which on the body-whorl become less distinct above the shoulder and are almost obsolete on the canal. Spiral ornamentation on the body-whorl consisting of twenty-two, and on the whorls of the spire about nine, nearly equal cords with narrow interspaces, which on crossing the axial ribs form nodes. Aperture ovate, forming a short, slightly twisted canal. Pillar nearly straight, covered by a thin coat of callus; with two broad, low plaits with wide interspaces. Dimensions: height, 34 mm.; diameter, 19 mm.

This variety has fewer axial ribs, shoulder is higher up on the whorls, upper surface of whorls more distinctly tabulate, and whorls enlarge more rapidly than the typical form.

Occurrence.—At locality 2964, on low hills near divide between Big Tar Creek and Garza Creek, near center of NE ¼ of NW ¼, sec. 7, T. 23 S, R. 17 E, M. D. B. & M., middle Etchegoin Pliocene. At the type locality this species occurs with a fauna including the following

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species: *Arca trilineata* Conrad, *Chrysodomus portolaensis* (Arnold), *Dendraster gibbsii* (Rémond), *Olivella biplicata* Sowerby, *Paphia staminea* (Carpenter), *Pecten,* cf. *healeyi* Arnold, *Pecten terminus* Arnold.

PECTEN ETCHEGOINI Anderson

Plate 7, figures 1 to 5

Pecten etchegoini Anderson, Proc. Calif. Acad. Sci., vol. 2, p. 198, pl. 18, figs. 92–93, 1905.

Pecten wattsi, var. *morani* Arnold, U. S. Geol. Surv. Prof. Paper 47, pp. 121–122, pl. 10, figs. 3–6, 1906.

Pecten wattsi Arnold, var. *etchegoini* Anderson, U. S. Geol. Surv. Bull. 396, p. 77, 1909.

On obtaining a large number of specimens from the type localities of *Pecten etchegoini* Anderson, *P. nutteri* Arnold, and *P. wattsi* Arnold a difficulty was at once experienced in attempting a separation of these forms. By closer study it was found that the prominence of the ribs of *P. etchegoini* varies greatly. Also the nodose constrictions characteristic of *P. wattsi* vary much in prominence. It became evident that series could be found for both valves showing a gradation of *P. nutteri* and *P. wattsi* into *P. etchegoini.* Figures are given in the present paper showing gradational series. *P. nutteri* Arnold and *P. wattsi* Arnold are therefore here used as variations of *P. etchegoini* Anderson.

SERPULA (?), sp.

Figure 2

On the south bank of Garza Creek, in the Coalinga district, is exposed a bed composed almost exclusively of tubules believed to represent the genus *Serpula.* The tubules are about 1.5 mm. in diameter and are closely packed together, forming an almost solid mass.

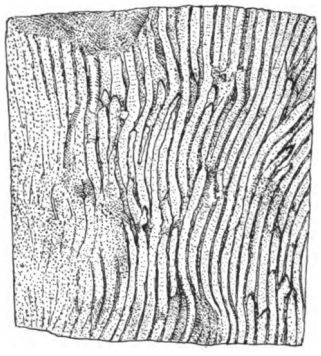

Fig. 2. *Serpula* (?), sp. × 2.

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[illegible]

[illegible] natural [illegible]

Fig. [illegible] *Pecten* [illegible]. Right valve from the type locality [illegible] formation [illegible].

Fig. [illegible] *Pecten* [illegible]. Left valve from the type locality.

Fig. [illegible] *Pecten* [illegible]. Profile view from the rear of the same specimen [illegible] showing [illegible] the left valve [illegible] from [illegible]

Fig. [illegible] *Pecten* [illegible]. Left valve of [illegible] from locality [illegible].

[illegible] *Pecten* [illegible] zone [illegible]

Fig. [illegible] *Pecten* [illegible]. Right valve from locality [illegible]

Fig. [illegible] *Pecten* [illegible]. Right valve from locality [illegible]

Fig. [illegible] *Pecten* [illegible]. Profile view from rear of same specimen as [illegible] immediately above ear.

Fig. [illegible] *Pecten* [illegible]. Left valve from locality [illegible]. *Pecten* [illegible] zone.

Fig. [illegible] *Pecten* [illegible]. Right valve of [illegible] from locality 2981. [illegible] *Pecten* [illegible] zone, upper [illegible].

Fig. [illegible] *Pecten* [illegible]. Profile view from rear of same specimen [illegible]

Fig. 4. *Pecten* [illegible] Arnold. Right valve from locality 2523. This [illegible] as a variety of *Pecten* [illegible] Conrad by Arnold.

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1b

2c

1a

2b

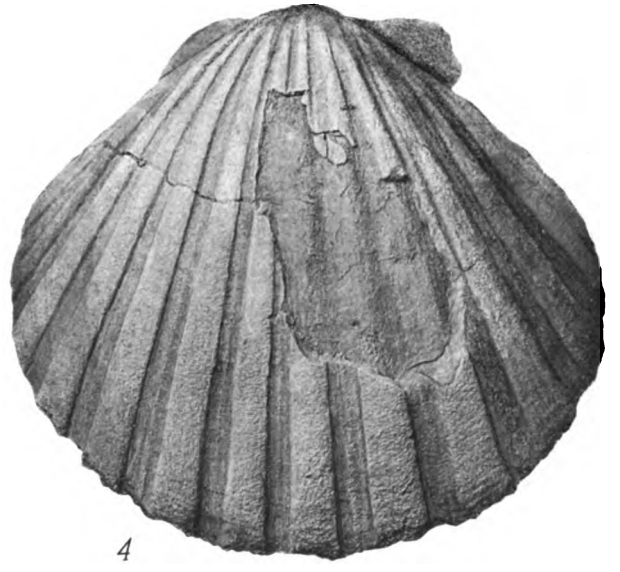
3

3a

3b

2

2a



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EXPLANATION OF PLATE 7

All figures natural size, left valve. Figures 1 to 4 from locality 2975.

Figures showing gradation of *Pecten wattsi* Arnold and *Pecten nutteri* Arnold into *Pecten etchegoini* Anderson.

Fig. 1. *Pecten etchegoini* Anderson. From the type locality of the species, Zapato Creek, Fresno County.

Fig. 1*a*. *Pecten etchegoini* Anderson.

Fig. 1*b*. *Pecten etchegoini* Anderson, or *P. etchegoini*, var. *wattsi* Arnold.

Fig. 1*c*. *Pecten etchegoini wattsi* Arnold. From the type locality of the variety, Zapato Creek, Fresno County.

Fig. 2. *Pecten etchegoini wattsi* Arnold.

Fig. 3. *Pecten etchegoini wattsi* Arnold, or var. *nutteri* Arnold.

Fig. 4. *Pecten etchegoini nutteri* Arnold. From the locality from which Arnold's material was obtained, Zapato Creek, Fresno County.

Fig. 5. *Pecten etchegoini nutteri* Arnold. From locality 2982.

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1c

1a

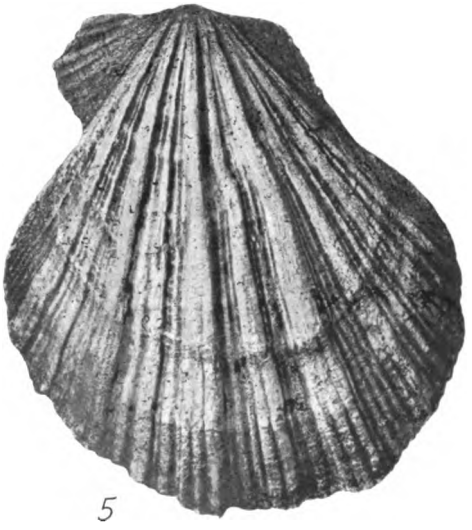
2

1

1b

3

4



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EXPLANATION OF PLATE 8

All figures approximately natural size

Fig. 1. *Cryptomya quadrata* Arnold. Right valve; from locality 3005, Priest Valley, Monterey County.

Fig. 1*a*. *Cryptomya quadrata* Arnold. Left valve; from same locality as figure 1.

Fig. 2. *Pecten etchegoini* Anderson. Right valve; from locality 3004, Priest Valley, Monterey County.

Fig. 2*a*. *Pecten etchegoini* Anderson, or *P. etchegoini nutteri* Arnold. Right valve of an intermediate form; from locality 3004.

Fig. 2*b*. *Pecten etchegoini nutteri* Arnold. Right valve; from locality 3004.

Fig. 3. *Macoma vanvlecki* Arnold. Right valve; from locality 2526, Jacalitos Creek, Fresno County.

Fig. 3*a*. *Macoma vanvlecki* Arnold. Left valve; from locality 2526.

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1

1a

2

3a

2a

3

2b

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EXPLANATION OF PLATE 9

All figures approximately natural size

Fig. 1. *Macoma inquinata affinis,* n. var. Left valve; no. 11092; from locality 2965, Garza Creek, Kings County, uppermost Etchegoin.

Fig. 1*a*. *Macoma inquinata affinis,* n. var. Right valve of same specimen as figure 1.

Fig. 1*b*. *Macoma inquinata affinis,* n. var. Profile view of valves shown in figures 1 and 1*a*.

Fig. 2. *Anodonta nitida,* n. sp. Left valve; a fresh-water species from locality 2999, no. 11091, Kettleman Hills, Kings County.

Fig. 3. *Semele fausta,* n. sp. Right valve; from locality 2991, Zapato Creek, Fresno County; no. 11102; Pecten coalingensis zone, upper Etchegoin.

Fig. 3*a*. *Semele fausta,* n. sp. Hinge of left valve; from locality 2991.

Fig. 3*b*. *Semele fausta,* n. sp. Hinge view of same specimen as figure 3.

Fig. 4. *Thracia formosa,* n. sp. Left valve; from locality 2991, Zapato Creek, Fresno County; no. 11103; Pecten coalingensis zone, upper Etchegoin.

Fig. 4*a*. *Thracia formosa,* n. sp. View of hinge of same specimen as figure 4.

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1

1b

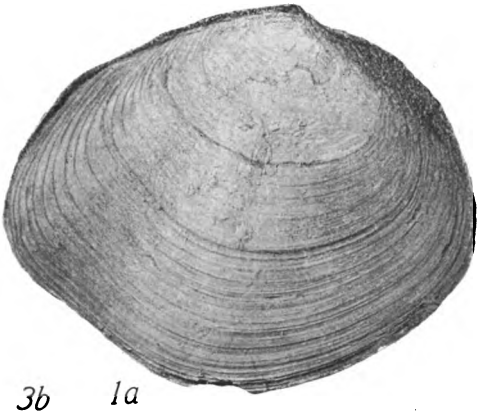
3

2

4

4a

3a



1a

3b

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EXPLANATION OF PLATE 10

Figures approximately of natural size

Fig. 1. ***Dosinia jacalitosana*** **Arnold. Exterior of right valve; from locality 3012, Priest Valley, Monterey County; lower Etchegoin.**

Fig. 1*a*. ***Dosinia jacalitosana*** **Arnold. View of hinge of right valve; from locality 3012.**

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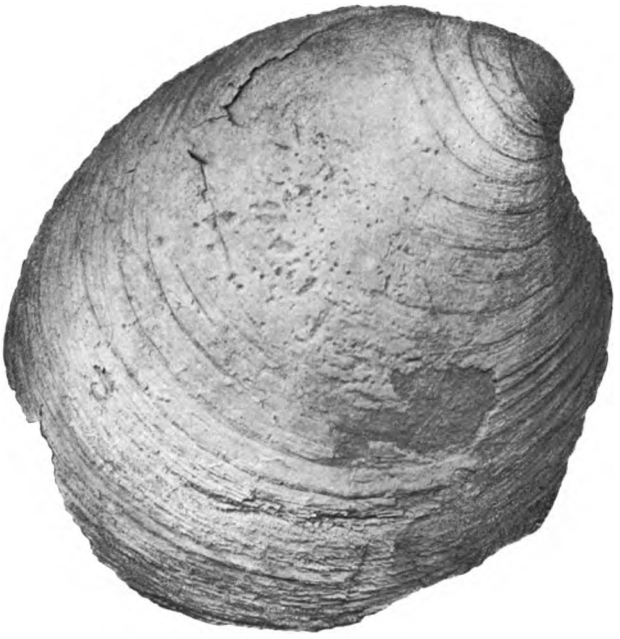

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EXPLANATION OF PLATE 11

All figures approximately natural size

Fig. 1. *Cancellaria rapa,* n. sp. Mouth view; no. 11097; Etchegoin Pliocene.

Fig. 1*a*. *Cancellaria rapa,* n. sp. Opposite view of same specimen as figure 1.

Fig. 2. *Epitonium varicostata* Stearns. Mouth view; from locality 2975, Zapato Creek, Fresno County; Pecten coalingensis zone, upper Etchegoin.

Fig. 3. *Fissuridea unica,* n. sp. Top view of type; no. 11100; from locality 2991, Zapato Creek, Fresno County; Pecten coalingensis zone, upper Etchegoin.

Fig. 3*a*. *Fissuridea unica,* n. sp. Side view of same specimen as figure 3.

Fig. 3*b*. *Fissuridea unica,* n. sp. Side view of a specimen of medium size; from locality 2991.

Fig. 4. *Purpura turris* Nomland. Mouth view; from locality 2680; occurs in both lower and upper Etchegoin.

Fig. 4*a*. *Purpura turris* Nomland. Opposite view of same specimen as figure 4.

Fig. 5. *Trophon belcheri avitum,* n. var. View of back; no. 11094; from locality 2988, Zapato Creek, Fresno County; middle Etchegoin.

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EXPLANATION OF PLATE 12

All figures approximately natural size

Fig. 1. *Cancellaria fernandoensis tribulis,* n. var. Mouth view; no. 11095; locality 2964, Garza Creek, Kings County; Turritella nova zone.

Fig. 1*a*. *Cancellaria fernandoensis tribulis,* n. var. Same specimen as figure 1 viewed from opposite side.

Fig. 2. *Murex tethys,* n. sp. Back view of type; no. 11099; from locality 2986, Zapato Creek, Fresno County, middle Etchegoin.

Fig. 2*a*. *Murex tethys,* n. sp. View of back of a small specimen; from locality 2643.

Fig. 2*b*. *Murex tethys,* n. sp. Mouth view of same specimen as figure 2.

Fig. 3. *Tegula* (*Chlorostoma*) *pulcella,* n. sp. From locality 2991, Zapato Creek, Fresno County; no. 11101; Pecten coalingensis zone, upper Etchegoin.

Fig. 3*a*. *Tegula* (*Chlorostoma*) *pulcella,* n. sp. Same specimen as figure 3; view of distorted and broken base.

Fig. 4. *Chrysodomus packardi,* n. sp. View of back of type; no. 11096; from locality 2958, Big Tar Creek, Kings County; middle Etchegoin.

Fig. 4*a*. *Chrysodomus packardi,* n. sp. Mouth view of distorted specimen from locality 2985.

Fig. 4*b*. *Chrysodomus packardi,* n. sp. View of back of specimen from locality 2958.

Fig. 5. *Turritella vanvlecki* Arnold. From locality 2377, the type locality of the species.

Fig. 6. *Murex concinna,* n. sp. Mouth view; no. 11093; from locality 2643, lower Etchegoin.

Fig. 6*a*. *Murex concinna,* n. sp. View of back of same specimen as figure 6.

Fig. 7. *Cancellaria crassa,* n. sp. Mouth view; no. 11098; from locality 2533, Waltham Creek, Fresno County; Turritella nova zone, middle Etchegoin.

Fig. 7*a*. *Cancellaria crassa,* n. sp. Back view of same specimen as figure 7.

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Vol. 10, No. 15, pp. 255-266, plate 13 Issued April 14, 1917

AGE OF STRATA REFERRED TO THE ELLENSBURG FORMATION IN THE WHITE BLUFFS OF THE COLUMBIA RIVER

BY

JOHN C. MERRIAM AND JOHN P. BUWALDA

UNIVERSITY OF CALIFORNIA PRESS
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INTRODUCTION

As a part of a programme of correlation studies on the Tertiary in the northern part of the Great Basin, the writers visited important localities of the Ellensburg formation of south-central Washington in June, 1916, in the hope of adding to the scanty representation of vertebrate remains known from these beds. A small collection was secured in the type area of the Ellensburg formation near North Yakima. A somewhat larger quantity of fragmentary material was collected in the great section of sediments appearing in the White Bluffs of the Columbia River in the vicinity of Hanford and Ringold, generally recognized as one of the largest of the typical Ellensburg exposures.

In the typical Ellensburg area near North Yakima remains of an equid or horse type were found representing the genus *Hipparion*,

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a group especially well represented in the earlier Pleistocene of western North America. From the White Bluffs localities the only determinable specimens representing the horse family belong to an advanced or specialized species of the genus *Equus*. In the widely known North American occurrences of *Equus* there is as yet no reported discovery of a species of such an advanced type in beds earlier than Pleistocene.

It is quite certain that the evolution stages of the horses represented by the Ellensburg and White Bluffs specimens belong to widely different periods, of which the White Bluffs stage is the later. The Ellensburg formation is evidently Miocene to early Pliocene in age; the White Bluffs exposures represent a distinct and considerably later stage in the history of sedimentation in the eastern Washington region.

It is the purpose of the following paper to give a brief statement concerning the physiographic and geologic features and the fauna of the White Bluffs exposures, which are here described as the Ringold formation.

Owing to brevity of the time spent in the Ringold area by the writers, data concerning structure of the formation, extent of the area occupied, and stratigraphic relations to the Ellensburg formation must be considered incomplete.

PREVIOUS KNOWLEDGE

The White Bluffs section was considered by I. C. Russell[1] "the most typical section of the John Day beds to be seen in Washington." As the name John Day was used by Russell with reference to the formation now known as the Ellensburg, it is to be presumed that he considered the White Bluffs approximately contemporaneous with the Ellensburg. The exposures were stated by Russell to range up to 500 feet in height, and to be composed of approximately horizontal or only slightly tilted strata. The beds were reported to consist of fine sands, clays, and strata of volcanic ash. A section taken at the southern end of the cliffs measured 496 feet in thickness.

Russell[2] reported that fossil bones of large animals had been found in the White Bluffs beds, but that their significance was not known. The exposures were considered favorable ground for collecting vertebrate remains. Reference was made to deposits presumed

[1] U. S. Geol. Surv. Bul. no. 108, p. 97, 1893.

[2] Ibid., p. 98.

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to be Pleistocene in the region occupied by the White Bluffs sediments, and the possibility noted of confusing Pleistocene and White Bluffs beds. Russell mentioned a locality at the southern end of the White Bluffs exposures, about fifteen miles above Pasco, where a number of large fossil bones, assumed to have been derived from the White Bluffs beds, were found in a river terrace banked against a cliff formed of horizontal White Bluffs strata. He stated that no molluscan shells were found in the sediments, and suggested the possibility that immense quantities of volcanic dust falling into the water may have made it unfavorable for animal life.

In 1903 George Otis Smith[3] referred to the White Bluffs exposures described by Russell, and called attention to evidence indicating that while in the Yakima region the Ellensburg formation is of fluviatile origin, farther east along the Columbia the formation is of lacustrine character.

Calkins[4] discussed the White Bluffs in 1905, and gave from the upper end of the cliffs a section 225 feet in thickness, consisting of sands and clays with some ashy material. Other writers were followed in correlating the White Bluffs exposures with the Ellensburg, but Calkins noted that "the general character of this section offers some points of contrast with the typical section measured in the Ellensburg Quadrangle." The materials included in the White Bluffs exposures were shown to be fine and less commonly cross-bedded than in the typical Ellensburg, and tuffaceous material was stated to be less abundant. The suggestion was made that a part of the White Bluffs beds may be of lacustrine origin, but that certain of the sandy layers were probably laid down in rivers. Calkins found no fossils in the White Bluffs exposures, but noted the reported occurrence of shells and bones in the bluffs near Pasco.

FAUNAS

In examining the White Bluffs in June, 1916, the authors collected mammalian material from exposures about midway between the base and the summit of the bluffs on the east side of the Columbia three to four miles below Hanford (loc. 3031). Later in the summer a small collection was secured one or two miles north of Ringold School (loc. 2757) a few miles south of the first locality.

[3] U. S. Geol. Surv. Professional Paper no. 19, p. 18, 1903.

[4] Calkins, F. C., U. S. Geol. Surv. Water Supply and Irrigation Paper no. 118, p. 35, 1905.

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The collection from the locality near Hanford (loc. 3031) includes the following forms:

Megalonyx, small species, probably new.
Equus or Pliohippus, calcaneum
Camelid, small, near Pliauchenia
Camelid, possibly larger than first mentioned form
Cervid, antler fragments
Leporid, new genus
Fish vertebrae and other elements of skeleton
Testudo, fragments

With the exception of the ground-sloth remains the material from locality near Hanford (loc. 3031) is not well preserved, and this form furnishes the only type diagnostic of any recognized faunal stage.

The *Megalonyx* specimen consists of a well-preserved maxillary with all four cheek-teeth in perfect condition. The species resembles the Pleistocene *M. wheatlyi* in size, but is probably new.

A single specimen representing the horse group consists of a considerably worn calcaneum or heel bone somewhat smaller than the average of calcanea of the Pleistocene horses, and exceeding little if any the average of *Pliohippus* from the West Coast Pliocene. It is considerably larger than the specimens commonly found in the West Coast Miocene.

Of the camel remains none of the fragments can be generically determined with certainty. A portion of a tooth and an incomplete proximal toe bone seem to represent a type not more advanced than those of the later Tertiary. They appear smaller and less specialized than the known forms of the West Coast Pleistocene.

Deer are represented by fragments of antlers, some of which show the burr well preserved. The deer of the Pleistocene and later Tertiary are not as yet well enough known to furnish a good basis for comparison of the fragments represented in the White Bluffs collection.

A single upper cheek-tooth of a rabbit-like form obtained in the White Bluffs beds is considered by Dr. Lee R. Dice to resemble in its tooth-pattern a new genus known from the middle Miocene and early Pliocene of northern Nevada. In this specimen the enamel folds on the re-entrant angle are comparatively coarse, in contrast to the finer folds seen in the teeth of the later rabbits.

The fish and tortoise remains have not shown characters furnishing definite evidence concerning geologic position.

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The material obtained one to two miles north of Ringold School (loc. 2757) includes upper and lower cheek-teeth and fragments of the skeleton of a horse in which all the characters noted are those of an advanced member of the genus *Equus*.

In the upper cheek-teeth the protocone is long anteroposteriorly, the anterior lobe projects far in advance of the isthmus connecting it with the protoconid, and the inner wall is markedly concave. The fossetts are narrow, and the borders show fairly complicated folds. In the lower cheek-teeth the inner faces of the protoconid and hypoconid are flat. The metaconid-metastylid column is long anteroposteriorly and broadly grooved internally. The valleys anterior and posterior to the metaconid-metastylid column are narrow transversely, as in *Equus*. The parastylid is short. A single splint bone representing digit four of the posterior foot is very short, and though the tip is absent the splint narrows so rapidly below that phalangeal elements must have been absent.

It is difficult to make certain of the specific identity of isolated *Equus* teeth, but the specimens from near Ringold School are at least as advanced as those of *Equus occidentalis* from the Pleistocene of Rancho La Brea, and may be even more specialized.

The assemblage of forms from the White Bluffs near Hanford taken as a whole seems more advanced than any fauna know heretofore in the Miocene of the Pacific Coast and Great Basin provinces. Megalonychid sloths are reported from the Pliocene, but are imperfectly known and of doubtful systematic position. Deer such as are represented in the collection are not known in Miocene beds of the Great Basin province. The earliest reported occurrence of typical deer in the region west of the Wasatch is in the latest Etchegoin Pliocene of the Coalinga region. The fragmentary camel remains might represent late Tertiary. They seem of earlier type than any known to the writers from the West-American Pleistocene. The fragmentary equid specimen might be from a late Tertiary or from a Pleistocene form.

The collection from near Ringold School taken by itself would be considered to represent Pleistocene.

The question of relative age of the material from the two White Bluffs localities naturally presents itself. There is some suggestion of difference in preservation between the two collections. The fossil specimens from near Ringold School show somewhat less evidence of corrosion and decay. In order to determine whether one collection might have been derived from the strata in the White Bluffs and the other from terrace deposits laid down against them, as reported by Russell [5] in the case of certain other deposits containing fossils at the

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southern end of the bluffs, both localities were carefully investigated. It was found that at both stations the bones were derived from layers of sand and gravel in the steep faces of the White Bluffs, a little below the middle of the exposed section, and that the strata yielding the fossils are part of the White Bluffs section and not terrace deposits. The locality one to two miles north of Ringold School is shown near the right-hand end of figure 1 in plate 13.

There is every reason for considering that the collections secured near Hanford (loc. 3031) and near Ringold School (loc. 2757) represent approximately the same horizon in the White Bluffs sediments. The best preserved specimens from both localities seem to furnish definite evidence of very late Cenozoic age. The ground-sloth jaw from the Hanford locality and the *Equus* teeth from the Ringold School locality both represent types generally considered characteristic of the Pleistocene.

As the separation between the Pliocene and Pleistocene is not yet clearly determined on a faunal basis in the Great Basin region, one might admit for the present the possibility of including in the latest Pliocene the faunal stage represented in the White Bluffs exposures. Not even the latest faunas referred to the Pliocene up to the present time includes horses of a stage as advanced as that of the Ringold School fauna, and the evidence on the whole favors Pleistocene rather than the latest Pliocene.

GEOLOGY

Stratigraphic Section.—From a point twelve miles above the town of Pasco, in south-central Washington, bluffs several hundred feet in height extend about thirty miles northwestward along the eastern bank of the Columbia River. Because of their light color these magnificent exposures have commonly been known as the White Bluffs.

The strata in the White Bluffs clearly represent a formation distinct from the Ellensburg, as is indicated by the difference in age expressed in their faunas, and by the physical evidence. The writers propose the name Ringold formation for these beds, from Ringold Post Office, situated at the base of the bluffs. The known thickness of these strata exposed by the downcutting of the Columbia River is approximately 500 feet; as the river has not reached the base of the section the total thickness is not known. The Ringold formation

[5] Russell, I. C., U. S. Geol. Surv. Bul. no. 108, p. 99, 1893.

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consists, as noted by earlier writers, chiefly of light-colored muddy sandstones and sandy clays, and in minor part of fine gravels, volcanic ash and calcareous strata.

The following is an estimated section of the Ringold formation in the White Bluffs three to four miles below Hanford:

	Feet
7. Loose yellowish clayey sand (summit of section)	85
6. Gray limestone, often brecciated, irregular in thickness, forming a resistant layer	3
5. Cream-colored clayey sandstone, lacking resistance to weathering	75
4. Brownish-yellow clayey sandstone, distinctly but thickly bedded, more resistant, standing out as bluffs	75
3. Yellow sandy clay, unindurated, poorly stratified	25
2. Cream-colored clay, thinly bedded, including occasional thin layers of sandy material, giving quite prominent outcrops	25
1. Nearly white clayey sandstone, in places pure sand, with occasional thin gravel layers of polished quartz pebbles. Fossils occurring near top of this member, which extends from the Columbia River up to an elevation of about 175 feet above the river	175
Approximate thickness of section exposed above Columbia River	503

Viewed from a distance individual beds may appear quite persistent in the face of the bluffs, but the bulk of the material is not thoroughly classified as to size, and therefore not sharply stratified. The coarser materials are waterworn. Occasionally beds of coarse angular materials, chiefly basaltic in character, are found at the top of the bluffs, but these are evidently later deposits laid down in channels cut in the Ringold by water courses heading in the country to the east and north. The strata of the Ringold lack induration and are notably softer than most exposures of the Ellensburg. While they exhibit steep slopes, especially where the Columbia has recently cut into the base of the bluffs, exposures tend to assume rounded outlines and a subdued topography, even under the prevalent conditions of semi-aridity.

Physiography and Structure.—Direct observations on the structure of the Ringold were limited to the White Bluffs exposures, but certain inferences as to the attitude of these beds in other parts of the area seem possible from physiographic considerations. So far as could be judged, the strata in the White Bluffs lie parallel to the water surface of the Columbia River. All recognized cases of apparent deformation seem to be due to landslide.

The White Bluffs follow the river closely from a point ten or twelve miles north of Pasco to the northwestward for about thirty

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miles. The bluffs end at a point across the river and a short distance below the town of White Bluffs. Where the beds are not locally reduced by erosion, the crest line of the bluffs is remarkably even (pl. 13, fig. 2). Without having determined its elevation above the river at many points, the crest appears to maintain its height of about five hundred feet above the stream throughout the whole thirty miles.

Between the northwestern end of the White Bluffs and Priest Rapids, a distance of fifteen to eighteen miles upstream, no high bluffs occur, but low light-colored exposures appear some distance from the river. The dissected character of this area indicates that it has suffered marked degradation in contrast to the relatively undissected areas lying to the east of the Columbia in the Ringold region. The more marked dissection has probably resulted from the greater drainage derived from the Saddle Mountains to the north.

The White Bluffs, extending along the east side of the Columbia River, have no counterpart in similar features on the opposite side of the stream. To the west of Hanford is an area with a rolling topography, on which occur occasional outcrops of soft beds similar to those in the White Bluffs. This area extends westward to the base of the Yakima Range and has a maximum width of perhaps sixteen miles. Practically all of it lies at less elevation above the Columbia than the top of the White Bluffs. It is believed that the Ringold once extended over this region of low hills between Hanford and the base of the Yakima Range, and that it was largely cut away by the Columbia before it had shifted eastward to its present position, and while its channel lay at a higher level. It has been this gradual shifting eastward, continued to the present time, which has produced the White Bluffs on the east side of the Columbia, in contrast to the degraded character of the area on the west side. The cause of the shifting cannot be stated with certainty, but it is probably due in part to deflection of the stream by the north side of the Yakima Range.

The surface extending several miles to the eastward from the summit of the White Bluffs is remarkably even, excepting where interrupted by occasional drainage courses which have cut below its level. The marked evenness and approximate horizontality of this surface as viewed from the summit of the bluffs, and the apparent absence of residual hills upon it, suggest immediately that it is a surface of aggradation rather than one of erosion or of river planation. Its striking parallelism, so far as the unaided eye may judge,

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with the strata of the Ringold in the face of the White Bluffs, strengthens this idea. Unfortunately extensive observations have not been made on the structure of the Ringold over more than a small portion of the area in which it is exposed, so that it cannot be stated with certainty that upturning and bevelling have not occurred in some of its marginal areas.

Mode of Deposition.—The available data indicate that the Ringold formation was deposited in a basin the walls of which were essentially the Yakima Range on the west, the Saddle Mountains on the north, and the lava plateaus on the east and south. It is probable that the flat area extending east from the White Bluffs and lying about five hundred feet above the Columbia is to be regarded as an undissected remnant of the aggradational surface developed at the close of the period of deposition, and indicates the elevation to which the basin was filled.

The Columbia cuts through high ranges like the Saddle Mountains instead of flowing around them, and is an antecedent stream in this part of its course; in pre-Ringold time its channel therefore lay across the area now occupied by these sediments. The presence of the Columbia in this region at the time the sediments were laid down, and the similarity of the sediments to those transported by the stream at the present day, make it probable that the Columbia deposited this formation. Whether the strata were laid down in a lake formed in the course of the stream, or as flood plain deposits, is not certain, as the limited time spent in the area did not permit an examination of the peripheral areas to determine the presence or absence of such evidence as beaches, bars, and other lacrustal features. The muddiness of the Ringold sandstones and the sandiness of the clays are, however, to be contrasted with the cleaner strata usually produced by the efficient classifying agencies of lacustral waters. The apparent scarcity or absence of freshwater molluscan remains, usually quite common in lacustral beds, and the presence at different localities of scattered bones of land mammals, also favor the belief that the deposits are largely of flood-plain origin.

Area.—Without having mapped its boundaries, the Ringold formation appears to the writers to occupy an area of at least 300 square miles, and may extend over 500 or 600 square miles. To the north the beds apparently reach to the lower slopes of the Saddle Mountains. Their eastward limit is not known, but it is certainly several miles to the east of the Columbia. Their southern boundary likewise has

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not been traced. As the Ringold deposits rise about 500 feet above the Columbia at the southern end of the White Bluffs, and the river has excavated a valley several miles wide south of this point, it is probable that the beds originally extended a considerable distance down the river, perhaps beyond Pasco. To the west the beds appear to be bounded by the base of the basaltic Yakima Range, which lies at distances from the river ranging up to fifteen miles or more. Considering the height to which the Ringold rises above the river in the White Bluffs region, it is probable that this formation originally extended up through the gap which the Columbia has cut across the Saddle Mountains, and that it was deposited over areas north of that range.

More precise data concerning the areal distribution of the Ringold and regarding its physiographic relations will be necessary before it will be possible to offer a satisfactory statement of the factors which caused the Columbia to deposit these sediments. From general considerations it is probable that the accumulation was due: (*a*) to an uplift across the course of the Columbia at some point downstream, or (*b*) to a subsidence of the region which the Ringold now occupies, or (*c*) to a change in the relation of the detrital load of the Columbia to its transporting power. The last condition might be associated with climatic fluctuations of the Glacial period or with marked changes in position of the course of the Columbia which are known to have occurred in the hundred miles or more of its channel north of the Saddle Mountains. Additional field-work, which the writers hope to carry out during a coming season, will be required before this problem can be solved.

Relation to the Ellensburg Formation.—In view of the difference in age between the Ellensburg and Ringold faunas it is important to know the stratigraphic relations of the formations in which they occur. It is probable that the two sets of beds come in contact on the western border of the Ringold, and perhaps at other points, but none of these localities have been examined. If the very even surface extending eastward from the White Bluffs be correctly interpreted as a remnant of the original surface of deposition, the Ringold strata probably lie approximately flat along the flanks of ridges consisting in part of folded Ellensburg strata. Such field data as have been obtained, taken with the palaeontologic evidence indicating difference in age, suggest unconformity between the two formations.

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STRUCTURE OF THE PES IN MYLODON HARLANI

BY
CHESTER STOCK

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STRUCTURE OF THE PES IN MYLODON HARLANI

BY
CHESTER STOCK

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Introduction

It is more than seventy years since the great British comparative anatomist, Richard Owen,[1] described the skeleton of *Mylodon robustus* from remains obtained in the Pampean Pleistocene of South America. In this masterpiece of exact observation and deduction there is included a discussion of the nearly complete manus and pes as they occur in that species. The figures[2] of *M. robustus* are by far the best available, illustrating the skeletal structure of the feet in the genus, and have been widely used as a basis for comparison with other mylodont material.

Since the publication of Owen's memoir, information concerning the mylodont sloths from the North American Pleistocene has grad-

[1] Owen, R., Description of the skeleton of an extinct gigantic sloth, Mylodon robustus, Owen, with observations on the osteology, natural affinities, and probable habits of the megatherioid quadrupeds in general, London, 4to., 176 pp., 24 pls., 1842.

[2] *Ibid.*, pls. 15 and 21 (see also pls. 16 and 22), 1842.

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ually accumulated and has received considerable addition within the past few years. Comparatively little is at present known, however, of the foot-structure in these forms. Fortunately the excellent and very abundant material of *Mylodon harlani* from Rancha La Brea, now in the palaeontological collections of the University of California and the Museum of History, Science and Art of Los Angeles, permits as complete an understanding of the manus and pes in the North American species as in the South American *M. robustus.*

During the course of an investigation of the structure of the pes in *Mylodon harlani,* certain differences between this species and *M. robustus* have presented themselves which apparently are not of specific character, but are due rather to a new interpretation of the elements involved in the former species. As there is reason for offering an interpretation of the foot-structure differing in a few particulars from that of Owen, the writer has attempted to present a reconstruction of the pes of *Mylodon* based upon the assembled foot material of *M. harlani* from Rancho La Brea. In this study Owen's description and figures of the pes of *M. robustus* have been particularly helpful.

Structure of Pes

In number of elements present the pes of *Mylodon harlani* is similar to that of *M. robustus.* It is worthy of note that in both species digit 1 and the internal cuneiform have totally disappeared. The presence of claws on digits 2 and 3 and the amount of reduction which has occurred in the fourth and fifth digits are as characteristic of the North American as of the South American species. Two distinctive differences, among others existing between the two species (see figs. 1 and 2), are at once noticeable in a comparative study of the pes:

(1) The relative size of the middle cuneiform and metatarsal 2; and (2) the size of the second and third phalanges of the median digit. These differences will be considered in greater detail below.

Tarsus.—The posterior border of the tuberosity of the calcaneum is more rounding than in *M. robustus.* The tendinal notch on the external side is larger than in the South American species and opens rather widely, while along the inner border the calcaneum, at approximately the middle, is much thicker dorsoventrally. The astragalus differs from that of *M. robustus* in the sharper angle between the two confluent articulating surfaces for the tibia. Lull[3] has described in

[3] Lull, R. S., A Pleistocene ground sloth, Mylodon harlani, from Rock Creek, Texas, Amer. Jour. Sci., vol. 39, pp. 375–378, 1915.

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detail the astragalus and navicular of *M. harlani* from Rock Creek, Texas, and they need not be considered further at this time. In *M. robustus* the cuboid is apparently longer anteroposteriorly than wide, while in *M. harlani* the reverse is true, the cuboid being wider transversely than long. The outer (lower) surface of the cuboid

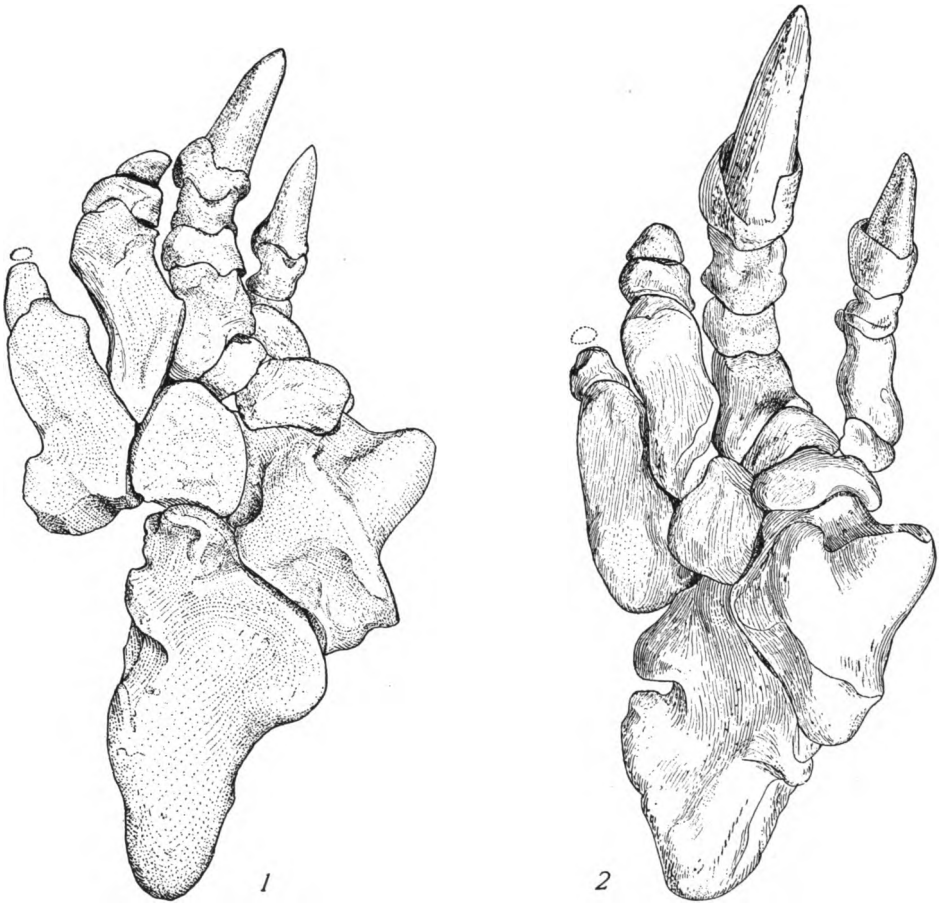

Fig. 1. *Mylodon harlani* Owen. Left pes, outer view, × ¼. Unguals slightly foreshortened. Rancho La Brea beds.

Fig. 2. *Mylodon robustus* Owen. Left pes, × ¼. After Owen. Pampean Pleistocene beds, South America.

articulates with a greater portion of metatarsal 5 and with a corresponding lesser portion of metatarsal 4 than in *M. robustus*. In the latter species there is a much smaller articulation of the posterior face with the calcaneum. This difference may also be more apparent than real.

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The external cuneiform does not differ essentially from the corresponding element described by Owen, but is smaller than that shown in the pes of *M. robustus*. An articular facet for the cuboid has not been observed on any of the specimens from Rancho La Brea, although some do show a facet on the inner side for the middle cuneiform. Owen[4] describes the latter element as follows:

> The internal of the two cuneiform bones is about half the size of the external one, and of nearly the same antero-posterior diameter, but more compressed laterally, and of somewhat less depth: its convex base is uppermost; its obtuse apex downwards: the inner and outer sides are nearly flat, rough, without trace of smooth articular surface, which is limited to the anterior and posterior extremities of the bone. The posterior surface is elliptical, slightly concave, adapted to the distinct circumscribed articular surface on the naviculare: the anterior articular surface is nearly circular, and very slightly convex. There is no articular surface upon the tibial or inner side of this cuneiform bone, nor any indication of a third or internal cuneiform on the os naviculare; from which it is to be concluded that the internal cuneiform bone and first toe, or hallux, were altogether wanting in the Mylodon, and that the mutilation by which its hind-foot is reduced to the tetradactyl type has commenced, according to the ordinary law, from the inner side.

In *Mylodon harlani* the middle cuneiform is compressed laterally and is roughly wedge-shaped (figs. 3*b* and 5) with the anteroposterior diameter of the rounded and narrow dorsal surface twice as great as the corresponding diameter ventrally. The depth of the cuneiform may be greater or less than the greatest anteroposterior diameter. The ventral surface is flattened and is wider transversely than the dorsal surface. The outer surface is flatter than the inner and, in all the specimens examined, bears along the proximal margin a facet for the external cuneiform. There is no indication of a facet along the proximal margin of the inner side for an internal cuneiform. The proximal articulating surface for the navicular is rectangular in shape and is slightly concave. At the distal end the articulating surface for the metatarsal is placed oblique to the vertical axis of the cuneiform. It is of greater dorsoventral diameter than the proximal articulation and is more deeply concave in that direction. The surface narrows dorsally and in most specimens is constricted at about the middle of the internal side. The middle cuneiform is noticeably larger than in *M. robustus*.

Metatarsus.—The second metatarsal in *M. robustus* is described by Owen[5] as follows:

[4] Owen, *op. cit.*, p. 121.

[5] Owen, *op. cit.*, p. 121.

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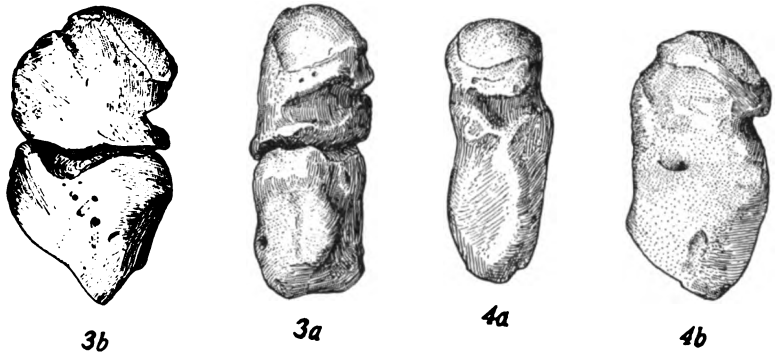
. . . a moderately long, subcompressed bone, having its proximal end obliquely truncated, and supporting a circular and nearly flat surface, below which there is a rough tuberosity. A narrow vertical channel with a large perforation in the middle, and with a convexity before and behind, characterizes the outer side of this bone; its inner side is rough and similarly unequal: on neither side is there the least trace of an articulation with an adjoining metatarsal. The distal end presents a simple ovate articular convexity, with the small end upwards.

As shown by Owen's figures,[6] metatarsal 2 is fully twice as long as the cuneiform with which it articulates.

In *Mylodon harlani* the second metatarsal differs decidedly from that of *M. robustus* in its relative length. This element, as contrasted with *M. robustus,* is exceedingly short anteroposteriorly, often shorter,



Figs. 3*a* and 3*b*. *Mylodon harlani* Owen. Middle cuneiform and second metatarsal, no. 22771, × ½. Rancho La Brea beds. Fig. 3*a*, superior view; fig. 3*b*, inner view.

Figs. 4*a* and 4*b*. *Mylodon harlani* Owen. Co-ossified middle cuneiform and second metatarsal, no. 22772, × ½. Rancho La Brea beds. Fig. 4*a*, superior view; fig. 4*b*, inner view.

in fact, than the middle cuneiform in *M. harlani.* In the marked shortening of metatarsal 2, the pes of the latter species may be construed as being more advanced than that of *M. robustus.* It is to be noted, however, that the middle cuneiform is relatively longer in *M. harlani* than in *M. robustus.*

The proximal and distal articulating surfaces of the second metatarsal may almost meet dorsally, giving the element a triangular shape in side view. In some specimens the proximal face is almost vertical and the metatarsal therefore approximates a quadrilateral form. The proximal articulating surface conforms in outline to the distal articulating surface of the cuneiform and may be convex below and slightly

[6] *Ibid.*, pls. 21 and 22.

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concave above. The distal articulation is elongate dorsoventrally, convex, and faces upward and slightly inward. The lower margin of the surface is straight. The inner side of the metatarsal is convex dorsoventrally, while the outer side, as in *M. robustus,* bears a narrow vertical groove, which joins below an excavation between the proximal and distal extremities.

A single specimen, no. 22772, representing a fusion of the middle cuneiform and metatarsal 2 in the pes of *M. harlani,* occurs in the collections at the University of California from the asphalt beds. All indications of an original separation are obliterated, although the two elements are easily recognized by their otherwise characteristic shape (contrast figs. 3*a,* 3*b,* and 4*a,* 4*b*). Along the proximal margin of the outer side in no. 22772 there is no distinct facet for the external cuneiform. The specimen is of special interest in its great similarity to Owen's figure and description of metatarsal 2 of *M. robustus.*[7] It suggests, at least, that in the latter species the second metatarsal as determined by Owen may possibly be the homologue of no. 22772 from Rancho La Brea.[8]

In *M. harlani* the third metatarsal articulates with more of the oblique proximal face of metatarsal 4 than in *M. robustus,* reaching half way across this face. The fourth metatarsal may be slightly longer than in the South American species. In the fifth metatarsal the large and heavy lateral process of the proximal end is well formed. It projects outward and backward more from the side of the metatarsal than in *M. robustus,* resembling in this respect *Scelidotherium. M. harlani* further agrees with the latter genus and differs from *M. robustus* in that the fifth metatarsal does not touch the calcaneum. It is possible, however, that in *M. robustus* some of these characters may be subject to intraspecific variation.

Digits.—Mylodon harlani agrees with its South American contemporary in the loss of the first digit, the presence of claws on digits 2 and 3, and the amount of reduction suffered by the fourth and fifth digits.

The second digit, as in *M. robustus,* consists of two elements.

[7] Owen, R., *op. cit.,* pls. 21 and 22. See also his description quoted above.

[8] Dr. W. D. Matthew, who very kindly examined for the writer the mylodont foot material in the American Museum of Natural History, states that the middle cuneiform in the feet of *Mylodon* in which it is preserved is much shorter than the second metatarsal. In this respect the second metatarsal agrees with Owen's figure, but the middle cuneiform appears to have a different shape. Dr. Matthew notes further that in the specimen of *Lestodon* the middle cuneiform and second metatarsal are co-ossified.

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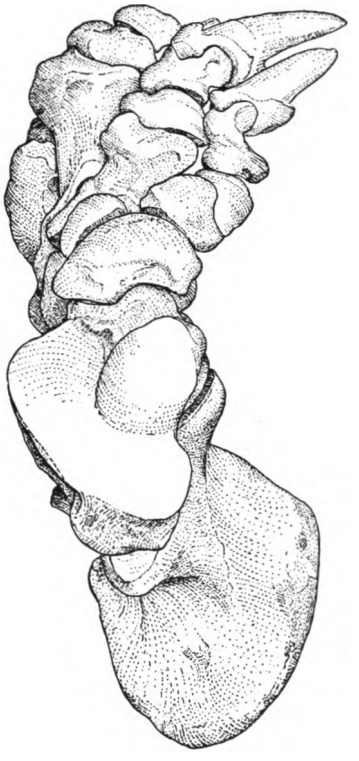
Fusion of the first and second phalanges has given rise to a single element, which is similar in shape to its homologue in the first digit of the manus, but is somewhat heavier and larger. Similarly the ungual is larger and heavier than the corresponding phalanx in digit 1 of the manus. The claw process of the ungual points inward.



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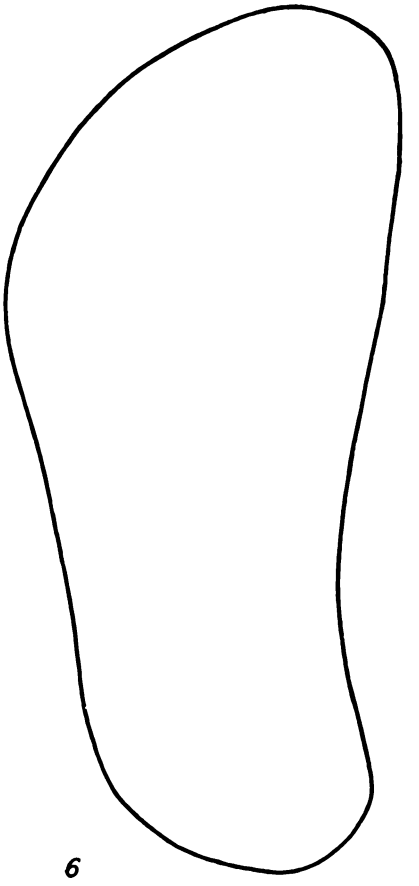

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Fig. 5. *Mylodon harlani* Owen. Left pes, superior view, × ¼. Rancho La Brea beds.

Fig. 6. *Mylodon.* Imprint of left pes, × ¼. Outline after Harkness. Pleistocene beds at Carson City, Nevada.

The height of the first phalanx of digit 3 is slightly greater than the basal width. The phalanx narrows but little dorsally from the base, agreeing in this character with the same phalanx in *M. robustus* and differing from the corresponding phalanx in digit 2 of the manus in the latter species and in *M. harlani.* It differs further from the

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first phalanx of digit 2, manus of *M. harlani,* in the much shorter anteroposterior diameter. This is due to the flatness of the two articulating condyles on the distal face for phalanx 2, and to the more shallow proximal concavity. The latter concavity, which receives the convex distal carina of the third metatarsal, narrows below. Along almost the entire inner side of this concavity is an offset which widens below, while at the lower end of the outer side a small offset is also present. In *M. robustus* Owen[9] describes the proximal face of the phalanx as "concave, adapted to the upper two-thirds of the convex trochlea of the metatarsal bone, and widening as it descends." Below each offset and on the ventral surface are two small facets for the sesamoids. Between these the ventral margin of the phalanx is broadly concave.

As interpreted by Owen, the characteristic features of the second phalanx, digit 3, of the pes of *M. robustus* and the corresponding phalanx of digit 2, manus, may be briefly tabulated as follows:

PHALANX 2, DIGIT 2, MANUS	PHALANX 2, DIGIT 3, PES
(1) Long in proportion to its breadth, which is greatest in the vertical diameter of its base.	(1) Anteroposterior diameter exceeds by one-eighth part the vertical diameter, and by one-third part the transverse diameter.
(2) Proximal articulation concave vertically, traversed by a median obtuse ridge.	(2) Proximal articulation consists of two vertical concavities separated by a median ridge. Upper extremity of latter ridge more produced than lower.
(3) Distal articulation describes a semicircle.	(3) Convex borders of distal trochlea describe two-thirds of a circle.

In dimensions and in structure of distal trochlea, the second phalanx of digit 3, pes of *Mylodon harlani,* differs from the corresponding phalanx of the pes of *M. robustus* and agrees more closely in these characters with phalanx 2, digit 2, manus of the latter species. This difference from Owen's interpretation is distinctly brought out also by a comparison with his figures (see figs. 1 and 2, also Owen, pl. 15). The depth of the proximal end of the second phalanx may be slightly less than or may exceed the total length of the phalanx in *M. harlani.* The second phalanx is often only half as large as the corresponding phalanx in the second digit of the manus. The proximal face is broad at the base and narrows dorsally to a posteriorly projecting process approximately one-half of the basal width. Some

[9] Owen, *op. cit.,* p. 123.

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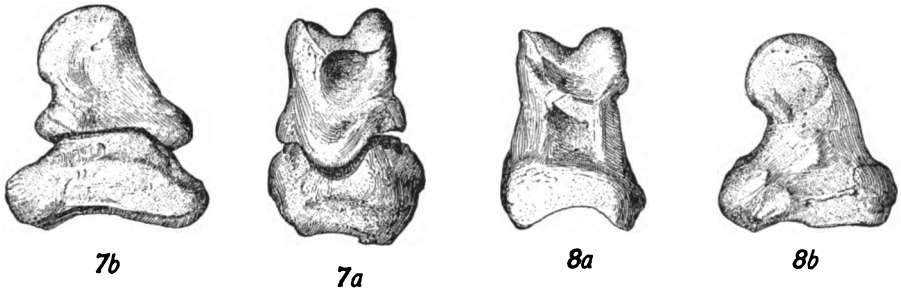
similarity to the corresponding phalanx of *M. robustus,* as interpreted by Owen, is thus shown by the backward projection of the dorsal end of the median ridge. The two flattened articulating surfaces of the proximal end are much less deeply excavated than in the corresponding phalanx of digit 2 of the manus. The articulation between the first and second phalanges allowed but little vertical movement. The external convexity of the distal trochlea has a greater depth than the internal, and its articulating surface is flatter. A certain amount of compensation for the outward twisting of metatarsal 3 is obtained through the articulations of the first and second phalanges, which tend to allow the ungual to play in a more nearly vertical direction.



Figs. 7*a* and 7*b*. *Mylodon harlani* Owen. First and second phalanges, third digit of pes, no. 22769, × ½. Rancho La Brea beds. Fig. 7*a*, superior view; fig. 7*b*, outer view.

Figs. 8*a* and 8*b*. *Mylodon harlani* Owen. Co-ossified first and second phalanges, third digit of pes, no. 22770, × ½. Rancho La Brea beds. Fig. 8*a*, superior view; fig. 8*b*, outer view.

Among the materials representing digit 3 of the pes of *Mylodon harlani* there are several specimens which were evidently formed by co-ossification of first and second phalanges (compare figs. 7*a*, 7*b* with 8*a*, 8*b*). The fused element is always somewhat shortened proximo-distally. A similar co-ossification occurs in the third digit, pes, of *Megatherium, Megalonyx,* and *Nothrotherium,* though it is worthy of note that in the Miocene genus *Hapalops* the two phalanges are separate. Among the Mylodontidae the same structure obtains in *Catonyx* and *Scelidotherium,* but the co-ossified element is broader and more fore-shortened than the Rancho La Brea specimens. The two phalanges are separate in *Lestodon, Pseudolestodon,*[10] and in *Mylodon robustus.* The lack of any great movement between the

[10] Rautenberg, M., Ueber Pseudolestodon hexaspondylus, Palaeontographica, Bd. 53, s. 1–50, 6 taf., 1906. This genus is considered by Lydekker as synonymous with *Mylodon,* by other authors with *Lestodon.*

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separate phalanges, together with the location of principal vertical movement between the first phalanx and the metatarsal in *Mylodon,* may be in part conducive to such co-ossification. It is more probable, however, that the co-ossification of the two phalanges in the genera cited above is to be correlated with the large ungual of the median digit, which prevails in these forms and requires a rigid support, while in *Mylodon* the relatively much smaller third ungual is accompanied by a more loosely articulating digit. Fusion of the two phalanges in *M. harlani* may depend upon the age of the individual.

In the identification of the foot material of *Mylodon garmani,* Dr. G. M. Allen,[11] who of necessity has followed Owen's determinations for *M. robutus,* has assigned to the second digit of the manus of the former species an element which is evidently identical with the structure under consideration. Allen[12] states:

> The phalanx next proximal to this [referring to the ungual of digit 2] is short, 53 mm. long, with two rounded facets anteriorly, and a broadly concave facet posteriorly. On each side of the latter, at its ventral corners, is a small squarish facet which evidently articulated with a sesomoid.

The character of the proximal and distal ends and the length of the phalanx establish its identity as the homologue of the co-ossified first and second phalanges in the third digit of the pes of *M. harlani.*

Characteristic features exhibited by the ungual of digit 2, manus, and digit 3, pes, of *M. robustus* as interpreted by Owen may be tabulated as follows:

Ungual, Digit 2, Manus	Ungual, Digit 3, Pes
(1) One-half the dimensions of ungual of digit 3, manus.	(1) Judging from figures, ungual much larger than that of digit 2, manus, and approaching terminal phalanx of digit 3 in size.
(2) Backward production of the upper part of the proximal joint permits claw-bone to be bent only downwards.	(2) In extreme extension, long axis may be parallel with that of second phalanx.
(3) Broad, rough, quadrilateral base of claw-sheath.	(3) Flat, rough, oval surface at the proximal half of base of claw.
(4) Claw-process conical, nearly straight, with an oblique base which gives under only half the length of the upper part.	(4) Claw-process forms chief part of ungual, conical, slightly deflected, inclined inwards. Under surface, owing to oblique line from which sides of ungual sheath arise, is less than half the length of the upper surface.

[11] Allen, G. M., A new Mylodon, Mem. Mus. Comp. Zoöl. Harv. Coll., vol. 40, pp. 319–346, 4 pls., 1913.

[12] *Ibid.,* p. 336.

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Ungual, Digit 2, Manus—(*Continued*)	Ungual, Digit 3, Pes—(*Continued*)
(5) Upper part of claw-process presents regular convexity from side to side, flattened toward apex, and divided by two sharp edges from less convex under surface.	(5) Claw-process convex above and at the sides; under surface convex transversely along its middle part, concave on each side. Claw-process for the extent of one inch and a half from its apex is impressed above with a shallow longitudinal groove.

A comparison of the characters presented by the ungual, digit 3, pes of *M. harlani,* with those above listed at once brings out a closer agreement, especially in size, with the ungual, digit 2, manus, than with the ungual, digit 3, pes, of *M. robustus* as interpreted by Owen.

The conclusion, therefore, seems inevitable that in Owen's reconstruction of the pes, as figured on plates 21 and 22 of the memoir on *Mylodon robustus,* the second and third phalanges of digit 3 have been interchanged with the corresponding phalanges of digit 2 of the manus. So far as is known to the writer, Owen's interpretation of these structures in *Mylodon robustus* has never been questioned.[13] Rautenberg,[14] in a study of the greater part of a skeleton of *Pseudolestodon,* describes and figures the pes and manus of that form. Although he recognizes the terminal claw of the third digit of the pes as the third largest of the ungual series, he has not noted the significance of this character when contrasted with *M. robustus.* In comparing the feet of *Pseudolestodon* with *M. robustus* Rautenberg[15] states:

> Die Fussknochen bieten bei den beiden zum Vergleich herangezogenen Gravigraden nur geringe Abweichungen. Hervorzuheben wäre, dass der Calcaneus bei *Mylodon* etwas kürzer und weniger breit erscheint, und dass die zweite und dritte Zehe bei *Pseudolestodon* nicht ganz die Grössenverhältnisse des *Mylodon* erreicht.

Again, in comparing the manus Rautenberg[16] writes as follows:

> . . . Ganz besonders in die Augen fallend ist die Grössenzunahme des zweiten und dritten Fingers, dessen fast gleichlange Krallen die übrigen um das Drei-

[13] During the course of completion of this paper the writer learned from Dr. W. D. Matthew that the changes necessitated by this new interpretation were already made in the mount of *Mylodon robustus* in the American Museum of Natural History. Mr. J. Z. Gilbert, who has studied the manus of *Mylodon harlani* from Rancho La Brea, reaches the same conclusion (MS. in press) from an interpretation of the second digit of the hand.

[14] Rautenberg, M., Ueber Pseudolestodon hexaspondylus, Palaeontographica, Bd. 53, s. 1–50, 6 taf., 1906.

[15] Rautenberg, M., *op. cit.,* p. 40.

[16] *Ibid.,* p. 41.

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fache übertreffen. Bei *Mylodon* ist einerseits die Kralle des zweiten Fingers nur halb so lang wie die des dritten, andererseits ist sie aber absolut kürzer als die entsprechende am Hinterfuss.

In the light of the new interpretation here presented of digit 3, pes of *Mylodon,* the ungual determined by Allen[17] as belonging to the second digit of the manus of *M. garmani* should be regarded as of digit 3, pes of that species. The ungual which has been determined as of the third digit of the pes by Dr. Allen,[18] following Owen, belongs to the second digit of the manus.

Digits 4 and 5 have suffered the same amount of reduction in *M. harlani* as in *M. robustus.* The first phalanx of digit 4 resembles in size the corresponding phalanx of digit 3, but differs greatly from the latter in general shape and in the nature of the proximal and distal articulating faces. The proximal face presents a vertical concavity to conform with the distal end of the metatarsal. Bordering the lower half of the inner margin of the proximal concavity and confluent with it is an articulating offset. The ventral margin of the phalanx below the concavity is notched and bears on each side a small facet for a sesamoid. The distal articulating face has been shifted inward, causing the first phalanx to be decidedly oblique with reference to a median vertical plane. This surface is concave transversely and of greatest depth along the inner side. Accompanying the obliquity of the phalanx is the greater length of the outer side, which is twice that of the inner.

The fifth metatarsal in *M. harlani* bore at the distal end a nodular rudiment, which in turn articulated distally with a much smaller element, as in *M. robustus.*

Comparison With Other Mylodont Genera

In the following comparison of the pes of *Mylodon harlani* with that of other mylodont genera, it is desired at present only to indicate such of the contrasting features as may be seen in the complete foot-structure of these forms. The comparative study of the pes of *Lestodon armatus* by Gervais[19] has been of much value in this connection, while the description of the foot-structure in *Scelidotherium*

[17] Allen, G. M., *op. cit.,* p. 336, pl. 3, fig. 9.

[18] *Ibid.,* p. 340, pl. 3, fig. 12. This interpretation of the unguals of *M. garmani* is also held by Mr. J. Z. Gilbert.

[19] Gervais, P., Mémoire sur plusieurs espèces de mammifères fossiles propres à l'Amérique Méridionale, Mém. Soc. Geol. France, Ser. 2, T. 9, Mém. 5, pp. 21–35, pls. 5–7 (pls. 25–27), 1873.

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leptocephalum by Burmeister,[20] and his comparisons with *Mylodon* and *Megatherium,* have been of greatest assistance. Reference should also be made to Owen's earlier observations[21] on *Scelidotherium.*

COMPARISON WITH LESTODON

The calcaneum in *M. harlani* differs from that in *Lestodon* in its greater constriction below the astragalus, and in the less broadly rounded posterior end. The tendinal groove on the outer border of the calcaneum is much better developed in *M. harlani.* An important difference between the two genera in the calcaneum, to which attention has been directed by Gervais, but which is not apparent in a comparison of the figures of the mounted pes of these forms, is the division of the astragalar facet. In this respect *Lestodon* is more like the Megalonychidae. Gervais also points out that in general shape the calcaneum of *Lestodon* is more like the corresponding element in *Megatherium.* In *Mylodon harlani* the angle between the inner and outer divisions of the tibial articulating surface of the astragalus is smaller than in *Lestodon.* Judging from Gervais' figure[22] of the pes of *L. armatus,* the outer or fibular side of the astragalus is not as deep as in *M. harlani.*

The navicular in the Rancho La Brea species is less compressed than in *Lestodon,* and the external cuneiform is thicker in the latter. In the latter also the middle cuneiform and the second metatarsal are fused, while in *M. harlani* these elements are usually separate. Gervais states that the third metatarsal is relatively much longer than in *Mylodon.*

In structure and size the second and third digits in the pes of the species from the asphalt are very close to *Lestodon.* The second digit is composed of two elements, the proximal one of which is a composite structure as in the latter. Digit 3 is composed of three elements; the two proximal phalanges are as a rule not co-ossified. In *Lestodon*

[20] Burmeister, H., Bericht über ein Skelet von Scelidotherium leptocephalum, Monatsberichte Akad. Berlin, pp. 374–381, 1 pl., 1881.

[21] Owen, R., Description of a considerable part of the skeleton of a large edentate mammal, allied to the Megatherium and Orycteropus, and for which is proposed the name of Scelidotherium leptocephalum. The zoology of the voyage of H. M. S. Beagle, etc., pt. 1, Fossil Mammalia, pp. 73–99, pls. 20–23, pl. 24, fig. 1, pl. 25, pl. 26, figs. 2, 4, and 6, pl. 27, pl. 28, fig. 2, 1840.

Owen, R., Description of the skeleton of an extinct gigantic sloth, Mylodon robustus, etc., pp. 126–137, 1842.

Owen, R., On the Megatherium (Megatherium Americanum, Cuvier and Blumenbach). Pt. V.—Bones of the posterior extremities, Philos. Trans. Roy. Soc. London, vol. 149, pp. 821–823, 1859.

[22] Gervais, P., *op. cit.,* pl. 7, fig. 6, 1873.

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there is no fusion of these phalanges. The ungual of this digit is comparable in size with that of *Lestodon,* and thus both agree in differing from *Megalonyx* and *Scelidotherium.*

The fifth metatarsal in *Lestodon* resembles that of *M. robustus* rather more closely than that of *M. harlani* in flatness of the outer side. The fourth and fifth digits in *M. harlani* have suffered a reduction similar to that in *Lestodon.*

COMPARISON WITH SCELIDOTHERIUM

Burmeister states that the calcaneum in *Scelidotherium* approaches in shape the genera *Megalonyx* and *Nothrotherium* rather than *Megatherium* and *Mylodon.* Owen had previously pointed out that "In the Scelidotherium the posterior termination of the calcaneum is broader, and terminated by a less angular convexity than in the Mylodon. . . ."[23] In the thickness of the tuber calcis *Scelidotherium* is more like other mylodonts and differs from *Megalonyx* and *Nothrotherium,* in which the posterior portion of the calcaneum is compressed and fan-shaped. With regard to the second largest of the ankle bones Owen states: "The astragalus of the Scelidotherium agrees with that of the Mylodon in the less depth of the middle division of the upper surface and the more open angle at which it joins the inner convexity. . . ."[24] It has already been pointed out[25] that the inner and outer divisions of the tibial articulating surface of the astragalus are separated by a more distinct angle in *M. harlani* than in *M. robustus.* The astragalus in *Scelidotherium magnum,* as shown by Winge,[26] is unquestionably more nearly like that in members of the Mylodontidae than that in the Pleistocene Megalonychidae. In the less open angle between the confluent articulating surfaces for the tibia the astragalus of this form resembles *Mylodon harlani* more closely than *M. robustus.*

In the pes of *Scelidotherium magnum* as given by Winge,[27] the internal and middle cuneiforms, with the former of which the first

[23] Owen, R., On the Megatherium, etc., p. 822. See also Owen, Description of the skeleton of an extinct gigantic sloth, Mylodon robustus, etc., p. 133.

[24] *Ibid.,* p. 821, 1859. See also Owen, Description of the skeleton of an extinct gigantic sloth, Mylodon robustus, etc., p. 132.

[25] P. 269.

[26] Winge, H., Jordfunde og nulevende Gumlere (*Edentata*) fra Lagoa Santa, Minas Geraes, Brasilien. Med Udsigt over Gumlernes indbyrdes Slaegtskab, E. Museo Lundii., Bd. 3, pt. 2, pls. 41 and 42, Copenhagen, 1915.

[27] Winge, H., *ibid.,* pp. 205–208, pl. 42, 1915.

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metatarsal is considered to be fused, and metatarsal 2 are present as separate elements. It is probable, therefore, that in Burmeister's figure the fused element represents more than the internal cuneiform and the remnant of digit 2. In *Mylodon harlani* the internal cuneiform has not been observed and from all appearances seems to have disappeared with the first digit. The additional loss of a functional second digit in *Scelidotherium* indicates a greater specialization in the pes than in *M. harlani*.

In discussing the relation of the cuneiforms to the adjoining metatarsals Burmeister states: ". . . bei *Mylodon* nur ein einziges, grosses cuneiforme sich findet, an welches die Metatarsusknochen von drei Zehen (I, II, III) stossen."[28] This is certainly not the case in *M. harlani* and, as shown by Owen, in *M. robustus* also, where the external and middle cuneiforms are separate elements supporting the third and second metatarsal respectively. That peculiar fusion of various bones of the pes is apt to occur is well shown in one of the skeletons of *Mylodon robustus* in the American Museum of Natural History, in which, according to Dr. Matthew, the external cuneiform is co-ossified with the third metatarsal.

In the marked widening and shortening of the third metatarsal and the presence of a heavy proximal segment in the digit which supports distally a very large ungual, *Scelidotherium* is decidedly different from *M. harlani* and is strongly suggestive of the Pleistocene Megalonychidae. The large ungual in *Scelidotherium* is supported by the co-ossified first and second phalanges, while in *Mylodon* the corresponding ungual is much smaller and is supported by first and second phalanges, which are usually separate. In the slender fourth metatarsal of the former genus the articulating faces for cuboid and metatarsal 3 are separated by a distinct angle, while in *M. harlani* they are continuous in the same plane. In *Scelidotherium* the three phalanges of digit 4 are represented. The proximal and middle elements have co-ossified, while the distal or terminal phalanx is rudimentary. In *M. harlani* only two segments of this digit are present, but the middle or second phalanx has not become fused with the proximal element. The reduction of the fourth digit in *Scelidotherium* is, therefore, not as advanced as in *Mylodon*. Burmeister believes that a closer agreement of *Scelidotherium* with *Megatherium* than with *Mylodon* is shown in that "die beiden Metatarsusknochen der zwei äusseren Zehen nur am cuboideum gelenken, und nicht, wie bei

[28] Burmeister, H., *op. cit.*, p. 380.

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Mylodon, der äusserste zugleich noch den calcaneus berührt."[29] In *M. harlani* the fifth metatarsal agrees more closely in shape with *Scelidotherium* than with *M. robustus,* and does not touch the calcaneum as in the latter species.

It is now generally conceded that *Scelidotherium* is a member of the Mylodontidae, a fact which is especially shown by the lobate character of the teeth. The present observations on the pes indicate that, with due allowance for variations in the individual elements of both genera, certain resemblances between *Mylodon* and *Scelidotherium* are closer than was supposed by earlier authors. Associated with these characters are modifications in *Scelidotherium* which remind one strongly of other Gravigrada.

Modification and Specialization of Pes

The twisting of the pes in *Mylodon harlani,* which brings the weight of the body to bear mainly upon the outer side of the foot, has profoundly affected the morphological structure. It has brought about a number of adaptations suited to a highly specialized type of locomotion. Several of the peculiar modifications to be noted in the pes of *Mylodon harlani,* some of which are of family, others of generic, distinction, may be listed as follows:

(1) Large and heavy calcaneum;

(2) Distinct angle between the confluent outer and inner divisions of the tibial articulating surface of the astragalus;

(3) Broadening and flattening, especially of the outer, posterior portion, of metatarsal 5;

(4) Reduction suffered by the fourth and fifth digits;

(5) Abbreviation of digit 3, with a much smaller ungual than in the corresponding digit of the manus;

(6) Abbreviation of the second digit and metatarsal, with which is associated a much smaller ungual than in the corresponding digit of the manus;

(7) Loss of digit 1 and the internal cuneiform.

One of the important modifications of the pes, lending itself to a comparative study, is that shown by the astragalus. In a description of the ground-sloths from the Santa Cruz Miocene deposits of Patagonia Scott has referred to *Nematherium* an astragalus which

[29] Burmeister, H., *op. cit.,* p. 380.

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he states[30] is "quite similar to that of the *Megalonychidae,* but a marked and suggestive likeness to *Mylodon* is seen in the trochlea; the inner condyle has a very distinct tendency to assume the odontoid shape and is much less extended proximo-distally than the external condyle." It is worthy of note that Scott considers the astragalus of *Prepotherium* as approaching that of *Megatherium* in the proximo-distal shortness and strong convexity of the tibial articulating surface and its prominent inward projection. Scott believes that in *Prepotherium* these characters indicate "a beginning had been made in the rotation of the foot, so as to bring the weight upon the fibular border."

The pronounced development of the odontoid, inner division of the tibial articulating surface of the astragalus in *M. harlani,* and the distinct separation between it and the outer division in the Rancho La Brea species indicate a greater specialization than in *Megalonyx* and *Nothrotherium.* It represents the result of a differentiation which had already commenced in the Miocene. The extreme modification of the astragalus in *Mylodon* would seem to suggest that the weight of the body was often supported by the posterior limbs alone. This is in accord with Owen's conception of the form as a browsing type, often resting its weight on the posterior extremities while using the anterior limbs to bring branches and foliage of trees within reach of the mouth.

Allowing for the new interpretation of the second and third phalanges of digit 3, the pes of *Mylodon harlani* is close in stage of evolution to that of *M. robustus.* In the distinct angle between the divisions of the tibial articulating surface of the astragalus, *M. harlani* is more advanced than the type of *M. robustus* as figured by Owen. This character is, however, somewhat variable in the North American species. A greater degree of advancement in *M. harlani* is suggested by the anteroposterior shortening of metatarsal 2, and the greater anteroposterior extension of the middle cuneiform than in *M. robustus.*

The co-ossification of the first and second phalanges of the median digit is characteristic of *Megatherium, Megalonyx, Nothrotherium,* and, among the Mylodontidae, of *Scelidotherium* and *Catonyx.* Fusion of the two phalanges has been noted in *Mylodon garmani* and may occur in *M. harlani,* but is apparently absent in *M. robustus.* In *Lestodon* and *Pseudolestodon* the two phalanges are separate. The widespread occurrence of this co-ossification among Pleistocene Gravi-

[30] Scott, W. B., Reports of the Princeton University Expedition to Patagonia, 1896–1899, vol. 5, pt. 1, Edentata, 3, Gravigrada, p. 350, 1904.

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grada is a distinctly more advanced character than the separation of the phalanges in the Miocene ground-sloths from the Santa Cruz beds. In the Pleistocene forms in which the co-ossification habitually occurs a large median ungual is present, while in *Mylodon,* where the first and second phalanges are usually separate, the ungual is tending to become reduced. The co-ossification of the two phalanges noted in *M. harlani* is presumably secondary and may be an age characteristic.

In *M. harlani* only two elements of the fourth digit are present, while in *Scelidotherium* the three phalanges are represented, the first and second having co-ossified and the third being rudimentary. In this respect *Mylodon harlani* is more advanced than *Scelidotherium.*

RELATION OF MYLODONT PES TO SUPPOSED HUMAN FOOTPRINTS IN PLEISTOCENE STRATA AT CARSON CITY, NEVADA

Occurrence of fossil footprints in Pleistocene strata at Carson, Nevada, first attracted scientific attention some thirty-five years ago. The imprints were uncovered in working the stone quarries of the Nevada State Prison. Joseph LeConte[31] in a description of these footprints states:

> The whole surface of the shale exposed in the prison yard is literally covered with tracks of many kinds, but the mud was so soft when the tracks were made that the nature of many of them can only be guessed. Some were probably those of a horse; some probably of a wolf; some certainly of a deer; many were those of long-legged wading birds. But the most interesting are those of the mammoth and the problematical so-called human tracks.

The supposed human footprints referred to by LeConte measured 18–20 inches in length and 8 inches in breadth. These tracks, occurring in associated right and left series, appeared to have been formed by a bipedal creature. They were considered by Harkness[32] to be impressions of the sandaled foot of primeval man. This belief created not a little discussion[33] at the time of its presentation. LeConte,[34] however, pointed out certain obvious objections to this interpretation, namely, the large size and the shape of the individual imprint and

[31] Letter to Nature, vol. 28, pp. 101–102, 1883.

[32] Harkness, H. W., Footprints found at the Carson State Prison, Proc. Calif. Acad. Sci., 7 pp., 5 diagrams, August 7, 1882.

[33] A delightful sketch written by the great American humorist, Mark Twain, on the "human" footprints at Carson, was published in *The San Franciscan,* February 16, 1884.

[34] LeConte, J., On certain remarkable tracks found in the rocks of Carson quarry, Proc. Calif. Acad. Sci., 10 pp., August 27, 1882.

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the span of the straddle as measured by the distance between right and left imprints. He considered the possibility that the tracks had been made by a bear or by a ground-sloth. In an addendum to the paper already referred to, LeConte mentions the suggestion of Marsh, that the supposed human imprints were perhaps formed by a ground-sloth, either *Mylodon* or *Morotherium*.[35] At that time remains of the latter forms were known to occur in Great Basin deposits of same age as the Carson strata. Marsh[36] compared the imprints with the pes of *Mylodon* and expressed an opinion in favor of their association.

The objections to the quadrupedal origin of the footprints were stated by LeConte to rest in "the apparent singleness of the tracks, and the absence of claw-marks." The first of these he explained by the observed fact that the imprint of the posterior foot is often superimposed upon that of the anterior foot, while he attributed the second peculiarity to "the clogging of the feet with mud."

From the present reconstruction of the pes of *Mylodon,* it is seen that the third digit did not bear a large claw as supposed by Owen. It follows that the possibility of obtaining a distinct impression of this claw is therefore also reduced. A comparison between the pes of *Mylodon harlani* from Rancho La Brea and the debatable footprints at Carson City (see figs. 5 and 6) reveals a remarkable similarity in size and general outline. This evidence is then in strong confirmation of the view expressed by LeConte and Marsh.

The common occurrence of *M. harlani* in Pleistocene deposits of North America makes it not improbable that the imprints at Carson belong to an individual of this species. The possibility remains, however, that the footprints were made by a ground-sloth other than *Mylodon. Megalonyx* and *Nothrotherium* are known to have been present in the Sierran region during the Pleistocene.

Conclusions

In the restoration of the pes of *Mylodon harlani,* based upon material from Rancho La Brea, the second and third phalanges of digit 3 are identified with the corresponding phalanges of digit 2, manus of *M. robustus,* as interpreted by Owen. In Owen's reconstruction of *M. robustus* the second and third phalanges of digit 2,

[35] This genus, as defined by Marsh, has been shown by the writer (Science, n. s., vol. 39, pp. 761–763, 1914) to be in part synonymous with *Mylodon.*

[36] Marsh, O. C., On the supposed human footprints recently found in Nevada, Amer. Jour. Sci., ser. 3, vol. 26, pp. 139–140, 1883.

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manus, have undoubtedly been interchanged with the corresponding phalanges of digit 3, pes.

A comparison of the pes of *Mylodon harlani* with that of *Scelidotherium* indicates certain resemblances between the two genera, which support their family relationship already suggested by the lobate character of teeth. In contrast to *Mylodon,* in which the first or inner digit is lost, the pes of *Scelidotherium* is markedly more specialized in the additional loss of a functional second digit. The latter genus differs further from *Mylodon* in the large size of the third ungual, agreeing in this character with other members of the Gravigrada, as, for example, *Megalonyx* and *Megatherium.*

The rotation of the pes toward the outer side has progressed much further in *Mylodon harlani* than in any of the Miocene ground-sloths from the Santa Cruz beds. This process is accompanied by a number of modifications adapted to a highly specialized type of locomotion.

With allowance for the differences in interpretation, the stage of evolution of the pes in *M. harlani* is near to that of *M. robustus.*

In size and general outline the pes of *Mylodon harlani* is remarkably similar to the supposed human footprints occurring at Carson, Nevada.

Transmitted December 15, 1916.

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AN EXTINCT TOAD FROM RANCHO LA BREA

BY
CHARLES LEWIS CAMP

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INTRODUCTION

The only amphibian remains so far discovered in the asphalt deposits of Rancho La Brea are those of toads. This material includes, besides remains of the species now inhabiting the region (*Bufo boreas halophilus*), some limb-bones, vertebrae and part of a skull of an undescribed species of toad now extinct. But few fossil salientians have yet come to light, and as the fragile nature of their bones makes it improbable that very many ever will be found, unusual value attaches to the present collection. The finding in the same Pleistocene deposits of numbers of beetles of a kind often fed upon by toads is significant; and the discovery of bones of toads in the Pleistocene in as great numbers as in the Recent localities would seem to mean that toads were then as abundant in the region as they are today.

The extinct species here described seems closely related to the Recent *Bufo boreas,* a species ranging along the Pacific Coast from southeastern Alaska to San Diego, California. There is unfortunately some question as to the exact locality of occurrence of the type skull of the fossil toad, and hence as to whether it is really a Pleistocene form; but a parasphenoid from Pleistocene locality 2051 corresponds exactly with the type of the new species, and differs, as does the type, from the single parasphenoid from Recent locality 2052, and from *B. boreas.* Measurements of the parasphenoid from locality 2052, in addition to other skeletal measurements (see table II), seem to show that the toad from that locality resembles *Bufo boreas* more closely than the extinct form.

BUFO NESTOR, n. sp.

Type specimen, a portion of a skull, No. 22468, Univ. Calif. Coll. Vert. Palae., consisting of all the anterior cranial, otic, and occipital elements intact except for slight damage to the left fronto-parietal. Locality 2051, Rancho La Brea, Los Angeles County, California.

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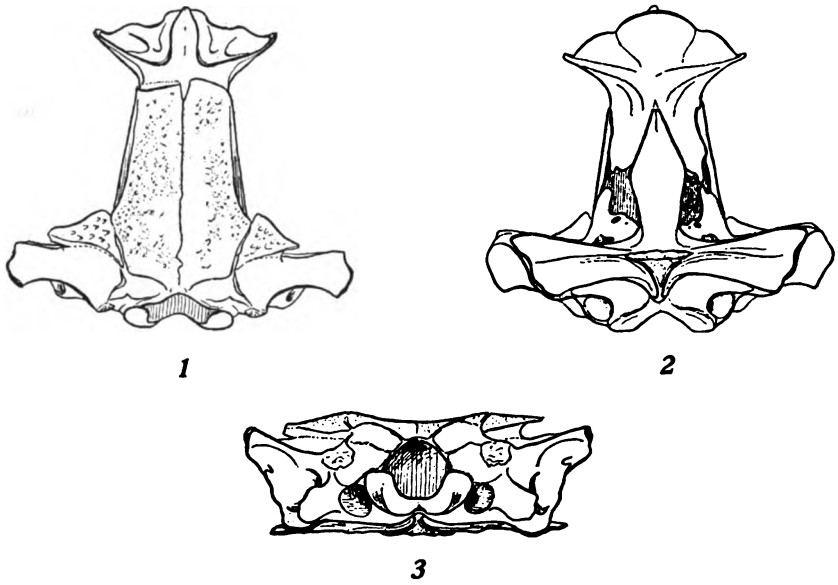
Fronto-parietals flat, not fused in midline, scarcely concave; dorsal surfaces considerably roughened; sides nearly parallel and projecting downward slightly around the cranium. Sphenethmoid relatively large, deeply notched posteriorly, nearly in contact with prootics behind and involving cranium in a more complete ossification than in Recent toads of related species. Short posterior arm of parasphenoid, pointed; anterior arm below cranium wider than in recent *Bufo boreas;* lateral wings below exoccipitals relatively and absolutely wider than in other species of the group; a strong trans-



Figs. 1–3. *Bufo nestor*, n. sp. Skull, No. 22468, × 2. Fig. 1, dorsal view; fig. 2, ventral view; fig. 3, posterior view. Rancho La Brea Beds, California.

verse ridge running medially through the lateral wings; a roughened triangular elevation below intersection of wings and shaft; outer anterior borders of lateral wing not upturned in contact with pedicel of pterygoid. Prootics extensively ossified, longer in proportion to width than in Recent western toads. Squamosals small, triangular, flat and roughened above; lying in the plane of the fronto-parietals and extending out above the prootics about half the length of the latter. Foramen magnum slightly wider than high; condyles meeting below; extending about half way up sides of foramen and overlapping edges of latter inside about 0.4 millimeter. "Condyloid" foramen relatively and absolutely greater in diameter than in skulls at hand of *Bufo boreas boreas* and *B. b. halophilus.*

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North American toads (*Bufo*) can be placed in three divisions: the *americanus-lentiginosus-cognatus* group with prominent angular head crests; the *debilis-punctatus-alvarius* section with crests low and curved around the orbits and with broad fronto-parietals; and the *boreas-canorus* group with no cranial crests (except in old adults) and with narrow fronto-parietals. It is to the latter division that the present species seems to belong. *Bufo nestor* differs from existing Pacific Coast toads, of the forms related to *B. boreas,* in its wider, flatter and more roughened fronto-parietals; longer and wider sphenethmoid; stouter and posteriorly pointed parasphenoid; flatter squamosals; mere slender prootics; larger and more completely protected brain-case.

Other material, consisting of toad bones, doubtless of the above described species, from locality 2051, Rancho La Brea, is as follows: Fourteen vertebrae; 2 third, 1 fifth, and 4 ninth (sacral); one pelvis; one ilium; eleven femora; twenty-four tibio-fibulae; fourteen humeri; five radio-ulnae; two complete and one fragmentary calcaneo-astragali; and one parasphenoid. In addition to the above, there is toad material, from locality 2052, consisting of seven vertebrae: 1 third, 2 fourth, 1 seventh, and 2 ninth (sacral); one ilium; twenty-one femora; thirty tibio-fibulae; twenty-two humeri; six radio-ulnae; two complete and two fragmentary calcaneo-astragali; and one parasphenoid.

The parasphenoid from locality 2051 agrees with the type in ratio of wing width to total length and in the pointed character of its posterior tip. It differs in the above characters from the parasphenoid from locality 2052 and from *B. b. boreas* and *halophilus.*

Femora from localities 2051 and 2052 and of existing *boreas* are almost indistinguishable. The largest are only about two-thirds the length of a frog femur of medium size (*Rana draytonii*), and all bear larger epiphyses than do corresponding bones of a specimen of spadefoot (*Scaphiopus h. hammondii*) at hand. The sigmoid curvature is more pronounced than in *Bufo woodhousii.* The smallest femur, from locality 2052, is much shorter than in *Hyla arenicolor,* but is thicker through the shaft. The largest specimens are longer than in any *B. b. halophilus* at hand and approach *B. alvarius,* but differ from that species in the more flattened character of the median ridge. A femur at hand of *B. b. boreas* from Vancouver Island is longer than any specimen from Rancho La Brea.

Seventeen humeri from locality 2052 do not differ greatly except in size from existing *B. b. halophilus.* The longest is one-fourth

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larger than the largest obtainable specimens of the existing forms and one-fifth longer than in the gigantic *B. alvarius,* which, however, is a short-armed species. These toad humeri differ from existing *Rana* in the greater expansion of the proximal ends, less degree of separation and lack of furrow ventrally (or posteriorly) between the middle rounded part and inner or post-axial condylar ridge of the distal end. Five of these seventeen humeri exhibit the cresta medialis of the male; the others, including the four largest, are probably from females. Five humeri, from locality 2051, do not differ materially from those of 2052, and existing species, except that they do not attain such a great size as those from locality 2052. Two show only the cresta medialis.

Radio-ulnae from the two Rancho La Brea localities show no perceptible differences in comparisons with specimens of *B. b. boreas* and *B. b. halophilus.*

Twenty tibio-fibulae from locality 2052 are very similar to specimens of *B. b. halophilus* at hand. They are not so strongly curved or so large as in *B. alvarius,* not so small as in *B. punctatus,* differ from *B. woodhousii* in the plate-like character of the ventral part of the proximal epiphysis, differ from *Rana* in the greater ratio of length to breadth, and from *Scaphiopus* in greater thickness.

Seventeen tibio-fibulae, from locality 2051, are almost indistinguishable from those occurring at locality 2052.

Portions of two ossa innominata from 2051 resemble examples of *B. b. boreas* and *halophilus* in all characters but height of the ilium at its widest part. The Rancho La Brea specimens, perhaps referable to *B. nestor,* exhibit a higher, heavier ridge on this bone (which approaches the condition found in some of the Ranidae), furnishing better attachment for the powerful extensor, leaping muscles in the hind legs.

Two sacral vertebrae from locality 2052 are procoelous and similar to *B. b. halophilus* and *boreas,* one is as large as in a specimen of *B. alvarius,* another smaller than in the largest *B. b. halophilus* at hand. The diapophyses are in each case strongly dilated. The angle the anterior edges of the diapophyses would make with one another when joined is less than 180 degrees. A sacrum from locality 2051 is small and seems relatively thicker and narrower than the corresponding bone in *B. b. halophilus.*

The calcaneo-astragalus from locality 2051 seems to bear no distinctive peculiarities.

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TABLE I

Skull Measurements of Bufo in Millimeters

Measurement	B. nestor, n. sp. No. 22468 Rancho La Brea	B. b. halophilus (?) Loc. 2052 Rancho La Brea	B. b. halophilus No. 4338, Mus. Vert. Zool. Los Angeles Co., Calif.	B. b. halophilus No. 1390, C. L. C. Los Angeles Co., Calif.	B. b. halophilus Berkeley, Calif.	B. b. boreas No. 2473, Mus. Vert. Zool. Humboldt Co., Nev.	B. b. boreas No. 2464, Mus. Vert. Zool. Vancouver Island, B. C.
Total width between outer ends of prootics	22.7	.....	22.7	19.6	23.2	21.0	22.2
Total length of fronto-parietal	14.0	.....	13.5	12.6	14.8	12.9	13.7
Extreme width of fronto-parietals	9.0	.....	8.9	9.0	10.3	7.4	8.6
Width of fronto-parietals behind orbits	8.5	.....	7.8	7.0	8.0	7.5	8.5
Width of fronto-parietals at anterior end	6.7	.....	6.0	5.3	6.4	5.3	6.6
Difference between last two measurements	1.8	.....	1.8	1.7	1.6	2.2	1.9
Length of sphenethmoid	10.5	.....	6.4	8.1	7.8	7.9	6.3
Width of sphenethmoid	11.5	.....	8.5	7.9	9.1	9.7	9.0
Total length of prootics	8.0	.....	8.0	6.4	8.2	6.1	7.2
Width of prootics, median	2.8	.....	3.0	2.8	3.0	2.4	3.7
Difference between last two measurements	5.2	.....	5.0	3.6	5.2	3.7	3.5
Height of cranium on middle line	7.4	.....	7.1	6.8	7.8	7.1	7.0
Height of cranium at outer edge of fronto-parietal	7.9	.....	7.9	7.2	9.2	7.8	7.9
Difference between last two measurements	.5	.....	.8	.4	1.4	.7	.9
Width of foramen magnum, horizontal diameter	4.3	.....	4.1	3.7	3.9	3.9	5.0
Height of foramen magnum, vertical diameter	3.9	.....	3.7	3.9	3.6	4.5	4.3
Distance between outer edges of condyles	7.3	.....	6.8	6.4	6.9	6.9	7.9
Distance between "condyloid" foramina	6.5	.....	6.5	6.0	6.9	5.8	7.4
Diameter of "condyloid" foramen	2.0	.....	1.2	1.0	1.8	1.5	1.6

	No. 22468	Another specimen					
Total length of parasphenoid	13.2	.....	12.7	12.4	12.3	15.1	13.8	13.9
Total width of parasphenoid	19.6	18.0	16.3	18.2	17.3	20.1	17.3	18.9
Greatest width of anterior arm of parasphenoid	3.6	.....	3.0	2.9	2.9	3.4	3.3	3.2
Greatest width of wing of parasphenoid	2.9	2.9	2.4	2.5	2.1	2.6	2.0	2.6

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TABLE II

Skeletal Measurements of Bufo in Millimeters

Bone	Measurement	B. nestor, n. sp. Locality 2051 Rancho La Brea	B. b. halophilus (†) Locality 2052 Rancho La Brea	B. b. halophilus No. 4338, Mus. Vert. Zool. Sierra Madre, Calif.	B. b. halophilus No. 1390, C. L. C. Pasadena, Calif.	B. b. halophilus Berkeley, Calif.	B. b. boreas No. 2473, Mus. Vert. Zool. Nevada	B. b. boreas No. 2464, Mus. Vert. Zool. Vancouver Island, B. C.	B. alvarius No. 3737, Mus. Vert. Zool. Imperial Co., Calif.	B. nestor, n. sp. Locality 2051 Rancho La Brea
Femur	Total length, average of all La Brea specimens	27.2+	27.2—	29.5	26.9	30.8	30.9	34.6	35.7	.....
Femur	Length of shortest of La Brea specimens	22.9	21.4	.....	.....	.....	.....	.....	.....	.....
Femur	Length of longest of La Brea specimens	31.3	32.0	.....	.....	.....	.....	.....	.....	.....
Tibio-fibula	Total length, average of all La Brea specimens	27.1	26.1	29.8	26.3	29.8	29.8	32.8	35.0	.....
Tibio-fibula	Length of shortest of La Brea specimens	22.2	20.6	.....	.....	.....	.....	.....	.....	.....
Tibio-fibula	Length of longest of La Brea specimens	31.0	30.8	.....	.....	.....	.....	.....	.....	.....
Humerus	Total length, average of all La Brea specimens	25.2	26.6	27.1	25.8	29.6	27.0	29.4	28.4	.....
Humerus	Length of shortest of La Brea specimens	22.6	19.6	.....	.....	.....	.....	.....	.....	.....
Humerus	Length of longest of La Brea specimens	28.2	32.0	.....	.....	.....	.....	.....	.....	.....
Radio-ulna	Total length, average of all La Brea specimens	18.2	16.3	19.1	20.0	20.2	20.1	20.5	19.2	.....
Radio-ulna	Length of shortest of La Brea specimens	13.5	13.6	.....	.....	.....	.....	.....	.....	.....
Radio-ulna	Length of longest of La Brea specimens	21.4	19.1	.....	.....	.....	.....	.....	.....	.....
Calcaneo-astragalus	Total length, one specimen	18.6	18.2	17.8	16.5	17.9	18.7	20.9	19.9	.....
Sacrum	Greatest length, one specimen	16.3	17.3	.....	.....	.....	.....	.....	.....	.....
Sacrum	Greatest longitudinal width, one specimen	4.9	4.9	.....	.....	.....	.....	.....	.....	.....
Pelvis	Greatest width or height of ilium, one specimen	3.0	3.0	2.7	2.2	3.0	2.7	2.8	3.5	.....
Pelvis	Greatest length of ilium, one specimen	34.0	39.6	33.7	29.7	38.5	37.0	36.6	39.0	.....
Pelvis	Ratio of maximum diameter (height) of ilium to greatest length of ilium	[Ratios below in per cent] 8.82	7.54	8.00	7.40	7.79	7.30	7.54	8.07	9.01
Parasphenoid	Ratio of width of anterior arm to total length	27.2	23.7	23.4	23.6	22.5	23.8	23.0	.....	.....
Parasphenoid	Ratio of width of wing to total length	22.0	18.8	20.4	17.1	17.2	14.5	18.7	.....	.....
Parasphenoid	Ratio of wing to total width	15.6	14.7	13.7	12.1	12.4	11.6	13.8	.....	16.1

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FAUNA OF THE SANTA MARGARITA BEDS IN THE NORTH COALINGA REGION OF CALIFORNIA

BY
JORGEN O. NOMLAND

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INTRODUCTION

Since the first description of the Santa Margarita in the San Luis quadrangle by Dr. H. W. Fairbanks, the question of age of this formation has from time to time attracted much attention. Especially important has been the relation of the Santa Margarita to the upper Miocene and Pliocene formations in the vicinity of San Francisco Bay. The Santa Margarita was considered by Fairbanks a division of the San Pablo, while a number of other geologists have thought it older than that group. The preservation of the fossils of the Santa Margarita at the type locality is very poor. Few attempts have been made to list a typical Santa Margarita fauna, and correlation with other localities has been uncertain or frequently impossible. A study of the Santa Margarita fauna has therefore become highly important for correlation purposes.

The present paper is a study of a fauna collected from beds in the north Coalinga region which have been correlated with the Santa Margarita. The palaeontologic studies apparently indicate that these beds represent the upper part of the San Pablo group. The faunas also indicate that they represent at least in part the same horizon as the Santa Margarita at the type locality.

Most of the material studied from the Coalinga region was collected by Dr. B. L. Clark during his research on the fauna of the San Pablo group. The writer is much indebted to Dr. Clark for the use of his field notes on the geology and for numerous valuable suggestions, especially in regard to correlation with the San Pablo fauna. Dr. R. E. Dickerson kindly permitted the writer the use of material in the collections of the California Academy of Sciences, San Francisco.

PREVIOUS PALAEONTOLOGIC AND GEOLOGIC WORK

The first published account of palaeontologic and geologic investigation in the region north of Coalinga was included in a paper published in 1905 by F. M. Anderson.[1] In this publication the Santa Margarita was grouped with what he called the Coalinga Beds. These beds comprised what was later mapped as Vaqueros, Santa Margarita, and Jacalitos formations by members of the United States Geological Survey. A brief general description of the geology with faunal lists

[1] Anderson, F. M., A stratigraphic study in the Mount Diablo Range of California, Proc. Calif. Acad. Sci., ser. 3, vol. 2, no. 1, 1905.

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was given. The age of the beds corresponding to the "Jacalitos" was regarded as uppermost Miocene.

In 1908 Anderson[2] published another paper including a description of the same region. The term Coalinga Beds was then modified so as to comprise a part of the "Jacalitos" and the Santa Margarita above the lithologic member called the Big Blue. It was suggested that the Coalinga Beds might be the equivalent of the San Pablo in the northern part of the Mount Diablo Range.

In the preliminary report on the Coalinga district by Ralph Arnold and Robert Anderson[3] in 1908, the Coalinga Beds as defined by F. M. Anderson were divided into Vaqueros, Santa Margarita, and Jacalitos formations. The name Santa Margarita was used because of the similarity of the fossils to those occurring in that formation in the San Luis quadrangle in San Luis Obispo County. This formation was believed to be of upper middle Miocene age. The Big Blue was tentatively included with the Santa Margarita.

In a bulletin by Ralph Arnold[4] on the palaeontology of the Coalinga district, a short list of species found in the Santa Margarita was given. The formation was believed to be at least in part older than the San Pablo.

The latest report on the geology and oil resources of the Coalinga district by Arnold and Anderson[5] does not differ essentially from their earlier reports on this region. It includes a general discussion of both the palaeontology and geology.

In the study of the palaeontology of the San Pablo group, B. L. Clark[6] compared that fauna to the forms found in the Santa Margarita. It was shown that nearly one-half of the species found in the Santa Margarita also occur in the San Pablo. It was also stated that this formation was the equivalent of only the upper part, the Astrodapsis whitneyi zone, of the San Pablo. A historical summary of the literature dealing with the San Pablo-Santa Margarita was included.

---

[2] Anderson, F. M., A further study in the Diablo Range of California, Proc. Calif. Acad. Sci., ser. 4, vol. 3, 1908.

[3] Arnold, Ralph, and Anderson, Robert, Preliminary report on the Coalinga Oil District, California, U. S. Geol. Surv., Bull. 357, 1908.

[4] Arnold, Ralph, Palaeontology of the Coalinga district, Fresno and Kings counties, California, U. S. Geol. Surv. Bull. 396, 1909.

[5] Arnold, Ralph, and Anderson, Robert, Geology and oil resources of the Coalinga district, California, U. S. Geol. Surv. Bull. 398, 1910.

[6] Clark, B. L., Fauna of the San Pablo group of middle California, Univ. Calif. Bull. Dept. Geol., vol. 8, no. 22, 1915.

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The most recent report on the geology of this section of the state is on the region north of the Coalinga district by Robert Anderson and Robert W. Pack.[7] The Big Blue is not included with the Santa Margarita, but is regarded as Vaqueros, this being based on fossils found in the region studied. The Santa Margarita is considered older than the San Pablo.

Relation to Other Formations

The Santa Margarita formation of the San Pablo group as mapped in the Coalinga district is found in two areas. The lithology of these two regions is decidedly different. West and southwest of Coalinga the formation consists almost entirely of a light-colored diatomaceous shale. This shale in many characteristics is very similar to the Monterey Shale found in many parts of the Salinas Valley. At some localities west of Coalinga a thin basal sandstone is found con-

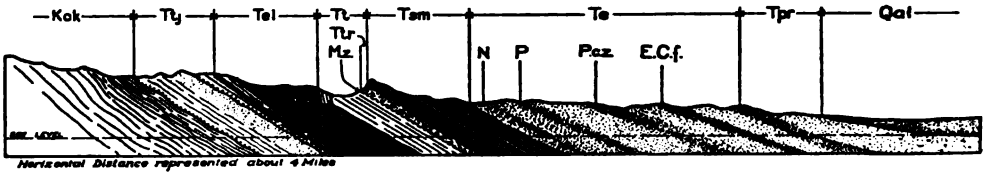

Fig. 1. Generalized section across formations on east side of Diablo Range, northeast of Coalinga. Kck, Cretaceous; Ttj, Tejon (Eocene); Tel, Oligocene; Tt, "Temblor" (Miocene); Tsm, Santa Margarita (Miocene); Te, Etchegoin (Pliocene); Tpr, Tulare (Pliocene); Qual, Pleistocene and Recent alluvium. (After Ruckman.)

formably below the shale.. From this member a small fauna has been obtained, which is the chief evidence favoring inclusion of this sandstone and the shale above with the Santa Margarita. The shale west and southwest of Coalinga rests with large discordance in dip on the Vaqueros and is overlain unconformably by the Etchegoin. In the other area which is found north and northeast of Coalinga, the Santa Margarita is lithologically quite different from the diatomaceous shale. The formation here consists entirely of soft yellowish sandstone which in many localities is highly fossiliferous. It is the fauna obtained from this area of Santa Margarita which will be described in the present paper.

As shown by the mapping of the region north of Coalinga by

[7] Anderson, Robert, and Pack, Robert W., Geology and oil resources of the west border of the San Joaquin Valley north of Coalinga, California, U. S. Geol. Surv. Bull. 603, 1915.

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Arnold and Anderson,[8] and by Anderson and Pack,[9] the Santa Margarita sandstone is continuous as a thin series of beds flanking the eastern slopes of the Diablo Range from near the town of Oilfields to a short distance north of Arroyo Honda. The formation is thus exposed for a length of somewhat more than twenty miles, being apparently overlapped in both the northern and southern ends by the younger Etchegoin. Another small exposure of the same formation composed of fossiliferous sandstone is also found a few miles northwest of Coalinga.

Considered as a whole, the Santa Margarita is decidedly distinct from the adjoining formations. At some localities, due to the similarity of lithology of the Santa Margarita near the base of the underlying lithologic member called the Big Blue, the line of contact is traced with difficulty. The Big Blue was therefore tentatively mapped with the Santa Margarita by Arnold and Anderson. The more recent work of Anderson and Pack[10] in the area north of the Coalinga district has shown that the Big Blue belongs with the Vaqueros and that it is unconformably related to the Santa Margarita. The Big Blue consists largely of deposits of serpentine detritus in part at least of land-laid origin. In the Coalinga district it is highly colored and is barren of marine invertebrate fossils. In the area north of the Coalinga district, however, Anderson and Pack report the finding of marine fossils in this member.

The Santa Margarita is similarly decidedly distinct from the overlying Etchegoin. As already stated by the writer elsewhere,[11] there appear to be good reasons for believing that the contact between the Santa Margarita and the Etchegoin is about two hundred feet stratigraphically lower than the line mapped by Arnold and Anderson. The beds containing fossil remains of the Pliocene horse *Neohipparion molle* Merriam would thus be included with the Etchegoin instead of the Santa Margarita. This will therefore be used as the base of the Etchegoin in the present paper. As thus defined, the beds lying immediately above the Santa Margarita have a number of characteristics indicative of terrestrial deposits. These beds are

[8] Arnold, Ralph, and Anderson, Robert, Geology and oil resources of the Coalinga district, etc.

[9] Anderson, Robert, and Pack, Robert W., Geology and oil resources of the west border of the San Joaquin Valley, etc.

[10] *Op. cit.*, p. 92.

[11] Nomland, J. O., Relation of the invertebrate to the vertebrate faunal zones of the Jacalitos and Etchegoin formations in the north Coalinga region, California, Univ. Calif. Publ., Bull. Dept. Geol., vol. 9, no. 6, 1916.

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highly colored, contain a large amount of silicified wood, leaves, and, as stated above, remains of land mammals.

As will be shown by a study of the accompanying list of species, faunally the Santa Margarita differs markedly from both the Vaqueros below and the Etchegoin above. Only a few of the species are found in the adjoining formations. The nearest correlative of the Santa Margarita appears to be the upper part of the San Pablo group[12] as developed in the northern part of the Diablo Range.

LITHOLOGIC SECTION OF THE SANTA MARGARITA NORTHEAST OF COALINGA

The sandstone member of the Santa Margarita as exposed in the area northeast of Coalinga was probably deposited, unlike the adjoining portions of the Vaqueros and Etchegoin, entirely under marine conditions. The following tabulated section indicates in a general way the lithologic character of the formation. It is to be

Fig. 2. Detailed section across the Santa Margarita about ten miles northeast of Coalinga. Horizontal distance about 2500 feet. (After Clark and Ruckman.)

borne in mind, however, that the beds vary greatly within a short distance and that the section can be applied in detail to only a very limited area.

DETAILED SECTION OF THE SANTA MARGARITA TEN MILES NORTHEAST OF COALINGA

	Feet
Etchegoin	
Basal gravel with silicified wood and gypsum. *Neohipparion molle* found short distance above base	
Santa Margarita	
Gray thin-bedded sandstone with well-rounded pebbles of brown chert, quartzite, and quartz monzonite	2
Buff to white, well-rounded, medium to coarse-grained sand	18
Hard, coarse, quartzose sand with pebbles of quartz monzonite, andesite, and rhyolite; cement calcareous	13
White to bluish-white, incoherent sand consisting chiefly of well-rounded quartz grains	50
Fossiliferous grayish-brown sandstone with well-rounded grains of quartz and feldspar	25

[12] Clark, B. L., Fauna of the San Pablo group of middle California, Univ. Calif. Publ., Bull. Dept. Geol., vol. 8, no. 22, 1915.

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	Feet
Hard grayish-brown sandstone; grains moderately well-rounded with pebbles of volcanic rocks	13
Barnacle reef, with arkose sand and large number of specimens of *Balanus*	1
Coarse, light-gray, pebbly sand with calcareous cement; pebbles subangular, chiefly andesite, quartz, and feldspar; fauna includes *Astrodapsis arnoldi, Ostrea vespertina*	30
Incoherent fossiliferous sand with large number of well-preserved specimens of *Mytilus kewi*	38
Bed of *Ostrea titan* in ashy sand	1
Fine ashy sand	25
Tuffaceous sand with *Ostrea titan*	1
Fine ashy sand with grains of quartz and feldspar	19
Ostrea titan in tuffaceous sand	1
A very persistent bed of bluish-gray water-laid volcanic ash. Unaltered feldspar, hornblende, and quartz; also volcanic type of biotite. All grains angular and broken	25
Unconsolidated gray sand consisting essentially of quartz, feldspar and biotite	19
Reef with numerous specimens of *Ostrea titan*	3
Very fine-grained arkose sand interstratified with layers of rhyolitic ash; has large number of crab borings	25
Bed consisting largely of shells of *Ostrea titan*	3
Fine gray sand with minute rounded grains of serpentine	57
Highly fossiliferous conglomerate composed mostly of shells of *Ostrea titan, Tamiosoma gregaria, Pecten estrellanus*	2½
Incoherent buff to brown arkose sand with minute fragments of serpentine	30
Basal coarse to medium-grained sand with well-rounded pebbles of serpentine; matrix chiefly orthoclase, and quartz; cemented by calcium carbonate	25
Total thickness	426½

Vaqueros

Big Blue serpentinous member.

Fauna of the Santa Margarita Northeast of Coalinga

In the report on the palaeontology of the Coalinga district by Ralph Arnold,[13] a brief Santa Margarita faunal list was included. This list comprised the following species:

Fossils from the Santa Margarita, Listed by Arnold

Astrodapsis whitneyi Rémond	Pecten crassicardo Conrad
Chione conradiana Anderson	Pecten estrellanus Conrad
Cryptomya ovalis(?) Conrad	Solen sicarius Gould
Dosinia ponderosa Gray	Zirphaea dentata Gabb
Hinnites giganteus Gray	Trophon carisaensis Anderson
Macoma nasuta Conrad	Tamiosoma gregaria Conrad
Ostrea titan Conrad	

[13] Arnold, Ralph, Palaeontology of the Coalinga district, Fresno and Kings counties, etc.

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The Santa Margarita formation northeast of Coalinga is in many localities exceedingly fossiliferous, although the number of species is usually not great. The species of most common occurrence are *Ostrea titan* Conrad, *Ostrea titan corrugata,* n. var., *Pecten estrellanus* Conrad, *Pecten crassicardo* Conrad, and *Tamiosoma gregaria* Conrad. A large number of the forms indicate that the Santa Margarita is closely related to the upper part of the San Pablo to the north. Among others may be mentioned the following species: *Dosinia arnoldi* Clark, *Dosinia merriami occidentalis* Clark, *Macoma diabloensis* Clark, *Mya dickersoni* Clark, *Pinna alamedensis* Yates, *Pinna bicuneata,* n. sp., *Cancellaria pabloensis* Clark, *Natica diabloensis* Clark, *Trophon carisaensis* Anderson. The species obtained from the Santa Margarita north of Coalinga in the collections studied by the writer include the following:

List of Species from the Santa Margarita North of Coalinga

	Vaqueros Temblor	San Pablo	Etchegoin	Recent
Echinodermata				
Astrodapsis californicus Kew (MS)	....	....	....	....
Astrodapsis coalingaensis Kew (MS)	....	....	....	....
Astrodapsis coalingaensis grandis Kew (MS)	....	....	....	....
Astrodapsis scutelliformis Kew (MS)	....	....	....	....
Bryozoa				
Several species	....	....	....	....
Pelecypoda				
Amiantis communis, n. sp.	....	....	....	....
Amiantis, sp. (large)	....	....	....	....
Cardium quadrigenarium Conrad	×	×	×	×
Chione semiplicatus, n. sp.	....	....	....	....
Dosinia arnoldi Clark	....	×	....	....
Dosinia merriami occidentalis Clark	....	×	....	....
Glycimeris, cf. coalingensis Arnold	....	....	....	....
Macoma diabloensis Clark	....	×	....	....
Macoma indentata Carpenter	....	....	?	×
Macoma nasuta (Conrad)	×	×	×	×
Macoma secta (Conrad)	×	×	×	×
Metis alta (Conrad)	×	×	×	×
Mya dickersoni Clark	....	×	....	....
Mya (Platydon) cancellatus Conrad	....	×	....	×
Mya (Cryptomya) ovalis Conrad	....	×	×	....
Mytilus kewi Nomland	....	....	×	....
Ostrea titan Conrad	?	×	....	....
Ostrea titan corrugata, n. var.	....	....	....	....
Ostrea vespertina Conrad	....	×	×	....
Panope generosum Gould	×	×	×	×
Pecten crassicardo Conrad	×	×	....	....
Pecten estrellanus Conrad	×	×	?	....
Pecten (Hinnites) giganteus (Gray)	×	....	×	×

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	Vaqueros Temblor	San Pablo	Eichegoin	Recent
Pecten hastatus Sowerby	....	....	?	×
Pecten raymondi Clark	....	....	....	....
Periploma clarki, n. sp.	....	....	....	....
Phacoides annulatus (Reeve)	?	×	×	×
Phacoides nuttalli (Conrad)	....	....	....	×
Phacoides sanctaecrusis Arnold	×	....	×	....
Pinna alamedensis Yates	×	×	....	....
Pinna bicuneata, n. sp.	....	×	....	....
Pitaria stalderi Clark	....	×	....	....
Psammobia, cf. edentula (Gabb)	....	....	....	....
Saxidomus nuttalli Conrad	×	×	×	×
Septifer margaritana, n. sp.	....	....	....	....
Siliqua lucida (Conrad)	....	×	×	×
Solen perrini Clark	....	×	....	....
Spisula, cf. catilliformis (Conrad)	....	....	....	....
Tellina, sp.	....	....	....	....
Venus, cf. martini Clark	....	....	....	....
Venus pertenuis Gabb	×	....	....	....
Zirphaea, aff. crispata (Linné)	....	....	....	....
Gastropoda				
Acanthina (Monoceras) norna, n. sp.	....	....	....	....
Calyptraea, cf. filosa (Gabb)	....	....	....	....
Calyptraea martini Clark	....	×	....	....
Cancellaria pabloensis Clark	....	×	....	....
Chrysodomus, cf. pabloensis Clark	....	....	....	....
Crepidula princeps Conrad	×	×	×	×
Ficus, cf. nodiferous Gabb	....	....	....	....
Liomesus, sp.	....	....	....	....
Nassa, sp.	....	....	....	....
Natica diabloensis Clark	....	×	....	....
Natica recluziana Petit	....	×	×	×
Natica recluziana andersoni Clark (MS)	....	....	....	....
Purpura nanna, n. sp.	....	....	....	....
Sinum scopulosum Conrad	×	....	×	....
Siphonalia danvillensis Clark	....	×	....	....
Tegula thea, n. sp.	....	....	....	....
Tegula varistriata, n. sp.	....	....	....	....
Trophon carisaensis Anderson	?	×	....	....
Trophon perelegans, n. sp.	....	....	....	....
Turritella freya, n. sp.	....	....	....	....
Turritella, sp. (large)	....	....	....	....
Cirripedia				
Balanus concavus Bronn	×	....	×	×
Tamiosoma gregaria Conrad	....	....	×	....
Pisces				
Fish vertebrae	....	....	....	....
Shark teeth	....	....	....	....
Number of species in common with the Santa Margarita	15	29	18	16

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OTHER SANTA MARGARITA LOCALITIES COMPARED

TEJON HILLS

In the Tejon Hills at the south end of the San Joaquin Valley, a fauna has been collected[14] which includes several typical Santa Margarita species. The fossils occur in coarse, white, arkose sand with lenses of clay and gravel. The pebbles consist essentially of rhyolite. The fossiliferous marine member is about 50–100 feet thick. Above this member is a formation consisting of reddish land-laid beds, the Chanac formation, in which remains of land mammals are found. A lower Pliocene horse, *Protohippus tejonensis,* has been described from the land-laid beds by Professor Merriam.[15] It resembles very closely a form listed by Arnold and Anderson[16] and by the writer[17] from near the base of the "Jacalitos" formation in the Coalinga region. The marine invertebrate fauna collected in the Santa Margarita of the Tejon Hills consists of the following species:

SANTA MARGARITA FAUNA FROM TEJON HILLS

Pelecypoda
- Dosinia cf. arnoldi Clark
- Metis alta (Conrad)
- Ostrea titan Conrad
- Ostrea, cf. vespertina Conrad
- Pecten crassicardo Conrad
- Pecten crassicardo biformatus, n. var.
- Pecten hastatus Sowerby
- Pecten raymondi Clark
- Phacoides richthofeni (Gabb)
- Phacoides sanctaecrusis Arnold
- Pinna alamedensis Yates
- Pitaria stalderi Clark
- Saxidomus nuttalli Conrad
- Siliqua, cf. lucida (Conrad)
- Solen, sp.
- Teredo, sp.
- Venus pertenuis Gabb

Gastropoda
- Bulla, sp.
- Calyptraea, sp.
- Conus, sp.
- Fusinus fabulator, n. sp.
- Nassa pabloensis Clark
- Natica, sp.

Pisces
- Shark teeth

SAN LUIS QUADRANGLE

A Santa Margarita fauna has been collected[18] from a sandstone member at the base of what has been mapped as Monterey shale by Fairbanks[19] in the San Luis Quadrangle. The sandstone is of a

[14] Tejon Ranch, about twenty miles southeast of Bakersfield, Caliente quadrangle; on west side of last large tributary of Tejon Creek, which cuts the Tejon Hills near north end, approximately western boundary of NW ¼ sec. 13, T. 32 S, R. 29 E, M. D. B. & M. Collected by Dr. B. L. Clark.

[15] Merriam, J. C., New horses from the Miocene and Pliocene of California, Univ. Calif. Publ., Bull. Dept. Geol., vol. 9, no. 4, p. 52, 1915. *Also:* Merriam, J. C., Mammalian remains from the Chanac formation of the Tejon Hills, California, Univ. Calif. Publ., Bull. Dept. Geol., vol. 10, no. 8, pp. 111–127, 1916.

[16] Arnold, Ralph, and Anderson, Robert, Geology and oil resources of the Coalinga district, etc.

[17] Nomland, J. O., Relation of the invertebrate to the vertebrate faunal zones of the Jacalitos and Etchegoin formations in the north Coalinga region, California, etc.

[18] Approximately northern boundary of sec. 18, T. 29 S, R. 11 E., M. D. B. & M. Collected by B. L. Clark.

[19] Fairbanks, H. W., U. S. Geol. Surv., San Luis Folio, no. 101, 1904.

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yellowish-brown color and has a thickness of about fifty feet. The basal conglomerate, containing numerous specimens of *Ostrea titan,* overlies serpentine of Mesozoic age in which are numerous *Pholas* (*?*) borings. A light-colored cherty shale rests conformably on the sandstone. The invertebrate fauna consists of the following identifiable forms:

SANTA MARGARITA FAUNA AT BASE OF "MONTEREY" SHALE

Astrodapsis tumidus Rémond
Mytilus, sp.
Ostrea titan Conrad
Pecten crassicardo Conrad
Pecten crassicardo biformatus, n. var.
Phacoides annulatus (Reeve)
Pholas(?), sp.
Psammobia, sp.
Spisula, sp.
Tamiosoma gregaria Conrad

In the northeastern part of the San Luis quadrangle a fauna has been collected[20] in a coarse white calcareous sandstone. The preservation of the fossils is very poor and usually only molds and casts are present. On comparison of this fauna with that of the upper San Pablo, a close relationship is apparent. The fauna from this locality, the type section of the Santa Margarita formation, was identified as follows:

SANTA MARGARITA FAUNA FROM THE TYPE SECTION

Echinodermata
- Astrodapsis margaritanus Kew (MS)
- Astrodapsis tumidus Rémond
- Astrodapsis whitneyi Rémond

Bryozoa
- Two species

Pelecypoda
- Arca trilineata Conrad
- Cardium quadrigenarium Conrad
- Cardita, sp.
- Chione, sp.
- Glycimeris, sp.
- Macoma, sp.
- Metis alta (Conrad)
- Mytilus, cf. coalingensis Arnold
- Ostrea titan Conrad
- Ostrea, sp. (small)
- Paphia, sp.
- Panope generosum Gould
- Pecten estrellanus Conrad
- Pecten raymondi Clark
- Phacoides nuttalli (Conrad)
- Pholas, sp.
- Psammobia, sp.
- Saxidomus nuttalli Conrad
- Schizothaerus nuttalli Conrad
- Solen, sp.
- Tellina, sp.
- Tivela, sp.

Gastropoda
- Astralium raymondi Clark
- Bulla, sp.
- Calyptraea martini Clark
- Calyptraea, sp.
- Chrysodomus, sp.
- Crepidula, sp.
- Murex, sp.
- Nassa, sp.
- Natica, sp.
- Olivella, sp.
- Trophon, sp.
- Turritella freya, n. sp.
- Turritella margaritana, n. sp.

Cirripedia
- Tamiosoma gregaria Conrad

Pisces
- Shark teeth

[20] At several localities on Santa Margarita Creek and Trout Creek, near the town of Santa Margarita, San Luis quadrangle. Type section of the Santa Margarita formation. Collected by R. E. Dickerson and W. Gordon.

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SALINAS VALLEY

The Santa Margarita is extensively exposed along the Nacimiento and San Antonio Rivers several miles west of San Miguel, San Luis Obispo County. The formation here consists of a grayish-white sandstone several hundred feet in thickness, resting on banded siliceous Monterey shale. The unconformity between these formations in this vicinity is very marked, so that while the Monterey has been intensely folded and faulted, the overlying Santa Margarita usually has relatively gentle dips. The lithology and included fauna indicate that this formation was here deposited near the ocean shore. From the distribution of these sandstones it is evident that the Santa Lucia Mountains were at this time above water and that the sediments must have been derived from this range. Also it is evident that following the folding of the Monterey, prior to or during Lower San Pablo time, this range was subjected to extensive erosion and probable mountain-making movements, while during the Upper San Pablo, or Santa Margarita time, an extensive transgression occurred. From the sandstones near the base on the north side of the Nacimiento River, about eight miles west of San Miguel, the following fauna was obtained:

SANTA MARGARITA FAUNA FROM NACIMIENTO RIVER

Bryozoa, sp.
Brachiopod, sp. A.
Astrodapsis antiselli Conrad
Astrodapsis margaritanus Kew (MS)
Calyptraea, sp.
Crepidula, sp.
Lima, sp.
Metis alta (Conrad)
Mytilus kewi Nomland
Ostrea titan Conrad
Ostrea titan corrugata, n. var.
Ostrea, sp. (small)
Pecten estrellanus Conrad
Pecten (Hinnites) giganteus (Gray)
Pecten raymondi Clark
Pecten sancti-ludovici Anderson and Martin
Pecten, sp. A.
Schizothaerus, cf. nuttalli Conrad
Trophon perelegans, n. sp.
Turritella, sp.
Balanus concavus Bronn

The Santa Margarita also has a large areal extent in the eastern part of Monterey County along tributaries entering the Salinas River from the east. Among these may be mentioned Cholame Creek, Vineyard Creek and Indian Valley. This formation at some localities shows exposures estimated at 1200–2000 feet, consisting essentially of shale in many respects lithologically similar to the Monterey. On Vineyard Creek in the lower portion of the formation, are found highly fossiliferous beds of sandstone and conglomerate with a typical Santa Margarita fauna. Above the Santa Margarita in this region

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are found sandstones and conglomerates of Lower Etchegoin age containing among other species several varieties of *Astrodapsis arnoldi* Pack.

Description of Species

AMIANTIS COMMUNIS, n. sp.

Plate 14, figures 2*a*, 2*b*, 2*c*, 2*d*

Type specimen, no. 11311, in Univ. Calif. Coll. Invert. Pal., from locality 2276, on hill near SW corner of SE ¼ of NE ¼ sec. 10, T. 19 S, R. 15 E, M. D. B. & M.

Shell large, rather thick, inequilateral, equivalve; umbones prominent, incurved, a little more than one-third of length of shell from anterior extremity. Anterior dorsal margin short, concave; posterior dorsal margin long, gently convex; ventral margin evenly arcuate; anterior end strongly curved; posterior extremity angulated. Lunule large and deep; escutcheon rather wide, extending nearly to posterior end, more strongly depressed on right than on left valve. Surface ornamented by numerous lines corresponding to stages of growth. Left valve with three cardinals and a lateral: anterior cardinal thin, close to middle cardinal. Right valve with bifid posterior cardinal. Nymph plates of both valves long and narrow. Dimensions: Height, 75 mm.; length, 82 mm.; thickness, 41 mm.

Pitaria diabloensis (Anderson) which also occurs in the Miocene of this region is somewhat similar in outline to this species, but may be distinguished from it by the long, narrow escutcheon, the smaller and shorter cardinal of the left valve, and the anterior and middle cardinals are nearer together.

Occurrence.—At localities 2276, 2278, northeast of Coalinga, Santa Margarita. At the type locality this species occurs with *Chione semiplicata,* n. sp.; *Periploma clarki,* n. sp.; *Septifer margaritana,* n. sp; *Acanthina norna,* n. sp.; *Tegula thea,* n. sp; *Tegula varistriata,* n. sp.

CHIONE SEMIPLICATA, n. sp.

Plate 15, figures 2*a*, 2*b*, 2*c*

Type in Univ. Calif. Coll. Invert. Palae., a nearly perfect specimen of left valve, no. 11318, from locality 2283, in small gully near SE corner of NW ¼ of NW ¼ sec. 15, T. 19 S, R. 15 E, M. D. B. & M., about nine miles northeast of Coalinga.

Shell subquadrangular to triagonal in outline; beaks prominent and strongly curved inwards, about one-fourth of length of shell from anterior end; interior margins faintly crenulate; anterior end

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approximately a right angle; flattened on sides of posterior portion of shell from beak to posterior dorsal margin. Anterior dorsal margin short and strongly concave; anterior ventral margin convex, becoming nearly straight near anterior end. Posterior dorsal margin long, nearly straight near middle, with increasing convexity towards ends; posterior ventral margin regularly arcuate. Lunule large, strongly depressed; escutcheon long, rather narrow. Surface of shell ornamented on sides by prominent concentric growth lines and radiating ribs of medium width. Middle and posterior cardinal tooth of right valve bifid; anterior cardinal small; nymph plates long and heavy. Posterior cardinal heavy, bifid; anterior cardinal long and rather narrow. Dimensions: Height, 71 mm.; length, 80 mm.

Chione temblorensis Anderson resembles *Chione semiplicata,* n. sp. The latter, however, may be readily distinguished by not having the marked depression on the sides at the posterior end and has more anterior beaks. From *Chione elsmerensis* English it differs in having shorter and more concave anterior dorsal margin, more convex ventral margin and weaker hinge.

Occurrence.—At localities 2276, 2283, in the Santa Margarita.

OSTREA TITAN CORRUGATA, n. var.

Plate 16, figure 1; plate 17, figure 1

Type a well preserved specimen of lower valve, no. 11309, in Univ. Calif. Coll. Invert. Palae., from locality 2284, near middle of southern boundary of NE ¼ sec. 10, T. 19 S, R. 15 E, M. D. B. & M., about fifty feet above base of formation.

Shell large, very heavy, when full grown sub-ovate but in earlier stages of very irregular outline. Surface sculptured by well marked growth lines which at the edges are irregularly folded into prominent radiating ridges. Ligamental groove wide, triangular, extending nearly across anterior end of shell. Muscular impression large, rectangular, almost invisible in type. Dimensions of lower valve: length, 235 mm.; width, 150 mm.; height, 120 mm.

Distinguishable from the typical *Ostrea titan* Conrad which is also found in the Santa Margarita formation by the prominent folds on surface and the greater convexity of lower valve.

Occurrence.—At locality 2284, Santa Margarita, about ten miles northeast of Coalinga, Fresno County; northern end of Huasna Valley, San Luis Obispo County; Vineyard Creek anticline, Monterey County.

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PECTEN CRASSICARDO BIFORMATIS, n. var.

Plate 18, figures 1, 1*a*, 1*b*; plate 19, figure 4

Type a well-preserved specimen of left valve, no. 11308, from locality 3029, near western boundary of sec. 13, T. 32 S, R. 29 E, M. D. B. & M., Tejon Hills, Caliente Quadrangle, Kern County.

Shell equilateral, equivalve, thin, rather compressed; with more or less serrate, regularly convex, basal margins. Right valve with about fifteen high, squarish, rather narrow ribs; interspaces considerably wider than ribs, both being ornamented by numerous fine radiating lines; surface sculptured by fine, almost invisible, imbricate lines; the larger specimens frequently show abrupt constrictions or undulations at later stages of growth. Anterior ear ornamented with incremental growth lines and about six radiating ridges; posterior ear smaller but otherwise similar to anterior. Left valve with about fifteen-seventeen high squarish ribs. These are wider than the interspaces or than the ribs of the other valve, ornamented with fine incremental lines; byssal notch well developed. Dimensions of type: Height, 92 mm.; length, 114 mm.; length of hinge line, about 65 mm.; umbonal angle, 110 degrees.

This species differs from the typical form in having higher and narrower ribs, especially in the left valve, and more compressed sides with abrupt constrictions.

Occurrence.—Locality 3029, Tejon Hills, Santa Margarita formation; San Pablo group, Concord quadrangle, Contra Costa County; Santa Margarita beds, San Luis quadrangle, San Luis Obispo County.

PERIPLOMA CLARKI, n. sp.

Plate 19, figure 6

Type, no. 11320, in Univ. Calif. Coll. Invert. Palae., from locality 2278, near center of sec. 15, T. 19 S, R. 15 E, M. D. B. & M., about nine miles northeast of Coalinga.

Shell of medium size, elliptical, thin, with right valve much deeper; left valve flattened. Umbones small, about three-fourths of length of shell from anterior extremity. Shell rather strongly produced anteriorly, angulated at anterior extremity; anterior dorsal margin gently convex; anterior ventral margin with slight angle near middle. Posterior portion of shell short; some specimens have depression extending from beak to posterior ventral margin, with distinctly biangulate end; posterior dorsal margin slightly convex; posterior

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ventral margin gently convex to nearly straight. Dimensions: Height, 32 mm.; length, 41 mm.; thickness, 14 mm.

This species resembles in a general way *Periploma argentaria* Sowerby. In *Periploma clarki,* n. sp., the shell is, however, higher and thicker in proportion to its length, the anterior end is much shorter, the posterior end is biangulate, and the posterior dorsal margin straighter.

Occurrence.—At localities 2276, 2278, 2279; Santa Margarita.

Named in honor of Dr. B. L. Clark of the Department of Palaeontology at the University of California.

PINNA BICUNEATA, n. sp.

Plate 15, figures 1*a*, 1*b*

Type in Univ. Calif. Coll. Invert. Palae., no. 11307, from locality 2284, near middle of southern boundary of NE ¼ sec. 10, T. 19 S, R. 15 E, M. D. B. & M., about fifty feet above base of Santa Margarita, ten miles northeast of Coalinga.

Shell elongate-cuneate; in cross-section thin, acutely elliptical. Hinge line long, nearly straight; ventral margin slightly concave near beaks; posterior end evenly rounded. Sculptured by approximately ten distinct radiating ridges which appear to be absent on lower one-third of shell.

Dimensions of type with broken posterior end: Length, 96 mm.; width, 44 mm.; thickness, 18 mm.; umbonal angle, 35 degrees.

This form may be distinguished from *Pinna alamedensis* Yates, which also occurs in the same beds, by its smaller size, long, straight hinge-line and ventral margin, less number of radiating ridges, and in being thinner in cross-section.

Occurrence.—In the Santa Margarita, locality 2284, near Coalinga; in upper San Pablo group, locality 1245, Las Trampas Ridge, Concord quadrangle, Contra Costa County; near Standard Oil Co. Powell well, eight miles northeast of Bradley, Monterey County, Lower Etchegoin (?).

SEPTIFER MARGARITANA, n. sp.

Plate 19, figure 5

Type in Univ. Calif. Coll. Invert. Palae., no. 11310, from locality 2276, on hill near SW corner of SE ¼ of NE ¼ sec. 10, T. 19 S, R. 15 E, M. D. B. & M.

Shell long, cuneate, rather thick; beaks pointed, terminal; with well-developed umbonal ridge extending to posterior ventral margin. Anterior dorsal margin slightly concave; posterior dorsal margin regularly convex; posterior end evenly rounded; ventral margin a little concave at middle but becoming convex about one-third of

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length of shell from anterior end. Surface ornamented by a large number of fine radiating ridges and well-developed growth lines. Dimensions: Length, 52 mm.; height, 22 mm.

This species is much larger than the Recent *Septifer bifurcatus* Conrad, the radiating ridges are more numerous, and the umbonal ridge is more marked.

Occurrence.—At locality 2276, Santa Margarita, about ten miles northeast of Coalinga.

ACANTHINA (MONOCERAS) NORNA, n. sp.

Plate 19, figures 3*a*, 3*b*

Type specimen, no. 11314, in Univ. Calif. Coll. Invert. Palae., from locality 2276, on hill near SW corner of SE ¼ of NE ¼ sec. 10, T. 19 S, R. 15 E, M. D. B. & M.

Shell of medium size, fusiform, six or seven whorls, spire elevated, with distinctly appressed suture and a slight constriction on each whorl a short distance below. Body whorl slightly flattened on sides with rather acute angulation at shoulder; ornamented below angulation by about eleven well-developed spiral cords between each pair of which occurs a small spiral line; at the shoulder a slight nodosity is evident. Whorls of spire with about five spiral ribs between each pair of which is a riblet; with about twelve well-developed axial ribs which become smaller at lower part of whorls. Aperture narrow elliptical; outer lip thickened, dentate; inner lip incrusted, slightly flattened; canal curved, of medium length. Dimensions: Height, 41 mm.; maximum diameter, 20 mm.

Occurrence.—At locality 2276, about ten miles northeast of Coalinga, Fresno County; Santa Margarita. At the type locality this species occurs with the following Santa Margarita forms: *Amiantis communis,* n. sp.; *Chione semiplicata,* n. sp.; *Periploma clarki,* n. sp.; *Septifer margaritana,* n. sp.; *Tegula thea,* n. sp.; *Tegula varistriata,* n. sp.

FUSINUS FABULATOR, n. sp.

Plate 20, figure 10

Type décolleté and broken specimen, no. 11319, in Univ. Calif. Coll. Invert. Palae., from locality 3029, near western boundary of sec. 13, T. 32 S, R. 29 E, M. D. B. & M., Tejon Hills, Caliente quadrangle, Kern County. Collected by R. C. Stoner.

Shell of medium size, fusiform, elongate, about five or six whorls, with a little increased convexity at shoulder; suture slightly appressed.

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Whorls crossed by about twelve prominent rounded ridges which are highest at shoulder and become nearly obsolete at the upper and the lower part of the whorl. Spiral sculpture on body whorl consists of approximately twenty distinct ribs with very narrow interspaces; whorls of spire with about eight spiral ribs. Aperture pyriform; canal broken. Dimensions: Maximum diameter, 28 mm.; height unknown.

Occurrence.—In the Santa Margarita, at locality 3029.

PURPURA NANNA, n. sp.

Plate 19, figures 1*a*, 1*b*

Type specimen, no. 11315, in Univ. Calif. Coll. Invert. Palae., from locality 2279, near center of SE ¼ of NE ¼ sec. 15, T. 19 S, R. 15 E, M. D. B. & M., about nine miles northeast of Coalinga.

Shell muriciform, thick, medium in size; with three prominent, thick, longitudinal varices on each whorl. Body whorl ornamented with six or seven well-developed spiral cords alternating with cords of less prominence; in the interspaces between the two series may be seen on well-preserved specimens one or two threadlets; at the shoulder between each pair of axial varices is a prominent node. Aperture acutely elliptical; outer lip thick, dentate along inner edge; inner lip with thin callus; canal in type closed, curved. Dimensions: Maximum diameter, 34 mm.; height of type, which has a broken spire, 51 mm.

This species resembles somewhat closely *Purpura foliata* Martyn; but has a somewhat more elongated form, stronger nodes between the varices, a development of fine threadlets between the spiral cords, and the varix on the front side of body whorl projects forwards, thus not having the flattened appearance evident on a front view of *Purpura foliata* Martyn.

Occurrence.—At locality 2279, in the upper part of the Santa Margarita.

TEGULA THEA, n. sp.

Plate 20, figures 6, 7*a*, 7*b*

Type specimen, no. 11317, from locality 2275, near SW corner of NE ¼ of NE ¼ sec. 33, T. 18 S, R. 15 E, M. D. B. & M., eleven miles northeast of Coalinga.

Shell conical; apex acute; suture slightly depressed; whorls about five, with flattened sides and well-marked shoulder. Body whorl ornamented by three broad spiral ridges of which the one near the

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base is narrower; between these are wide interspaces, the lower being of less width; both ridges and interspaces covered by nine or ten spiral threads, of which the one at the shoulder and the two at the base are wider and more prominent; above the shoulder are about five equal spiral lines; the oblique incremental lines crossing the spirals give the surface a slight nodose appearance. Base of body whorl convex, sculptured by about ten distinct concentric lines, which in general become finer away from the center. Aperture subcircular; outer lip rather thick; on inner lip is small tubercle; umbilicus open. Dimensions: Height, 16 mm.; maximum diametear, 22 mm.

Occurrence.—At localities 2268, 2275, 2276, 2279, 2283; Santa Margarita.

TEGULA VARISTRIATA, n. sp.

Plate 20, figures 4*a*, 4*b*

Type in Univ. Calif. Coll. Invert. Palae., no. 11316, from locality 2268, along side of cañon, SW corner of NE ¼ of NE ¼ sec. 15, T. 19 S, R. 15 E, M. D. B. & M., about nine miles northeast of Coalinga, Fresno County.

Shell conical, sides and upper part of whorls convex, about five whorls, with a slight shoulder on some specimens. Body whorl sculptured by about fifteen approximately equal spiral lines with narrower interspaces; oblique incremental lines intersecting spirals give a nodose appearance. Base of body whorl convex; ornamented by about eleven approximately equal concentric nodose lines. Aperture subovate; inner lip with small tooth or tubercle; umbilicus open. Dimensions of type: Height, 20 mm.; diameter, 21 mm.

In some respects this species resembles closely *Tegula thea,* n. sp. It may be distinguished from that form by the nearly uniform convexity and the lack of the three prominent ridges on the sides of the whorls.

Occurrence.—In the Santa Margarita at localities 2268, 2276, 2282.

TROPHON PERELEGANS, n. sp.

Plate 20, figures 1, 2, 3

Type specimen, no. 11321, in Coll. Vert. Palae. of Calif. Acad. Sci., San Francisco; from near Graham oil well, western boundary sec. 2, T. 19 S, R. 15 E, M. D. B. & M., about eleven miles northeast of Coalinga, Fresno County.

Shell of medium size; spire rather high; whorls about six; suture indistinctly appressed. Whorls with slight angle on each whorl, a little below the suture, above which the surface is gently convex; ornamented by about eleven thin axial varices which become spinose

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at angulation. Body whorl with well-marked groove at about middle of distance between angulation and end of canal; ornamented on the sides by about eight to ten distinct, subequal, spiral ridges which become almost obsolete immediately below the angulation; axial varices extend across groove down about one-half of length of canal. Aperture ovate; outer lip thin; with long, rather wide, recurved canal. Dimensions: Maximum diameter, 26 mm.; height unknown.

This species is apparently closely related to *Trophon coalingensis* Arnold. It may readily be distinguished from that form, however, by having a higher spire, longer canal, and less number of axial varices. From such forms as *Trophon stuarti* Smith and *Trophon gracilic* Perry, it differs among other characteristics in having the deep groove at lower part of body whorl.

Occurrence.—Rare in the upper Santa Margarita, northeast of Coalinga; Nacimiento River eight miles west of San Miguel, San Luis Obispo County; Vineyard Creek anticline, Monterey County.

TURRITELLA FREYA, n. sp.

Plate 19, figure 2

Type an imperfect specimen, no. 11313, from locality 2283, near SW corner of NW ¼ sec. 15, T. 19 S, R. 15 E, M. D. B. & M., Coalinga quadrangle.

Shell tapering rapidly, number of whorls unknown; with distinct, slightly impressed suture. Whorls flat with a wide ridge near middle; immediately above the suture are two prominent spiral cords with interspaces of about the same width; between the middle ridge and suture above, a slight tendency to depression is noticeable; ridges and interspaces covered by numerous, on the type twenty-five, narrow spiral striations; incremental lines indistinct. Aperture subcircular to nearly square. Dimensions: Maximum diameter, 16 mm.; height unknown.

Occurrence.—At locality 2283, northeast of Coalinga, near middle of Santa Margarita; locality 1697, about one-half mile north of town of Santa Margarita, in type section of the Santa Margarita.

TURRITELLA MARGARITANA, n. sp.

Plate 20, figure 5

Type specimen, no. 11312, in Univ. Calif. Coll. Invert. Palae., from locality 1706 at approximately middle of southern boundary of sec. 17, T. 29 S, R. 13 E, M. D. B. & M.; elevation about 1200 feet. San Luis quadrangle.

Shell medium in size; number of whorls unknown; sides of whorls approximately flat; suture distinctly impressed. Near the base are

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two heavy ribs, the upper being more prominent, the interspaces between these about the same width as the ribs; the rib next to the suture above of about same prominence as two near base; between the ribs at base and the one at top are two spiral lines with narrow interspaces. Incremental lines nearly invisible. Aperture quadrangular to subcircular. Dimensions: Maximum diameter, about 14 mm.; height unknown.

Occurrence.—At localities 1697, 1706, north of town of Santa Margarita, type section of the formation, San Luis Obispo County. This species occurs at the type locality with *Turritella freya,* n. sp.

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EXPLANATION OF PLATE 14

All figures approximately natural size.

Fig. 1. *Mytilus kewi* Nomland. Occurrence, in lower Etchegoin and Santa Margarita.

Fig. 2*a*. *Amiantis communis*, n. sp. Left valve; type specimen no. 11311; U. C. locality 2276; Santa Margarita.

Fig. 2*b*. *Amiantis communis*, n. sp. View showing lunule and escutcheon of same specimen as figure 2*a*.

Fig. 2*c*. *Amiantis communis*, n. sp. Interior view of right valve; from locality 2276.

Fig. 2*d*. *Amiantis communis*, n. sp. Interior view of left valve; locality 2276.

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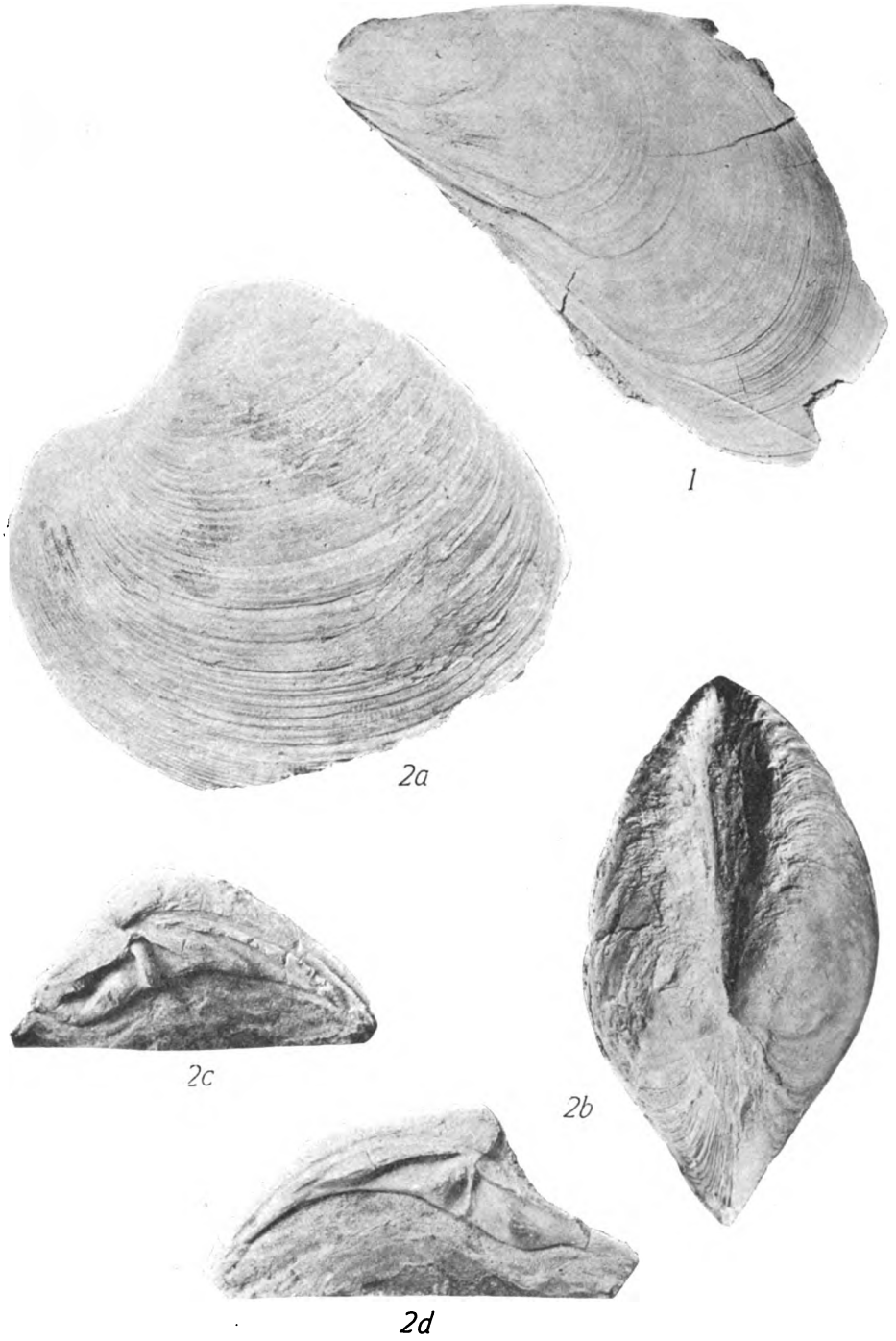

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EXPLANATION OF PLATE 15

All figures approximately natural size.

Fig. 1*a*. *Pinna bicuneata*, n. sp. View of right valve of type specimen 11307; from U. C. locality 2284; characteristic of upper San Pablo and Santa Margarita.

Fig. 1*b*. *Pinna bicuneata*, n. sp. Profile of both valves as viewed from the rear.

Fig. 2*a*. *Chione semiplicata*, n. sp. Exterior view of left valve of type specimen no. 11318; from U. C. locality 2283; Santa Margarita.

Fig. 2*b*. *Chione semiplicata*, n. sp. Interior view of left valve.

Fig. 2*c*. *Chione semiplicata*, n. sp. View of interior of right valve.

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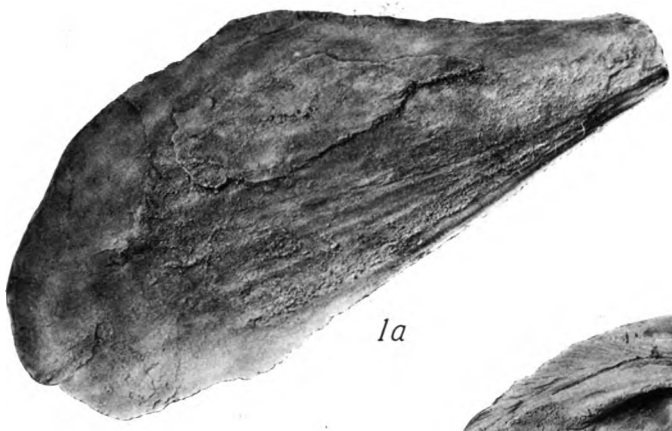

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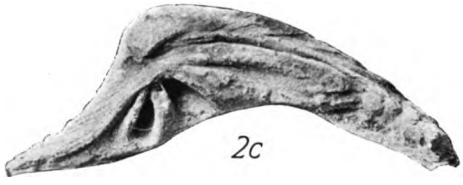

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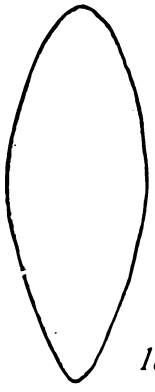

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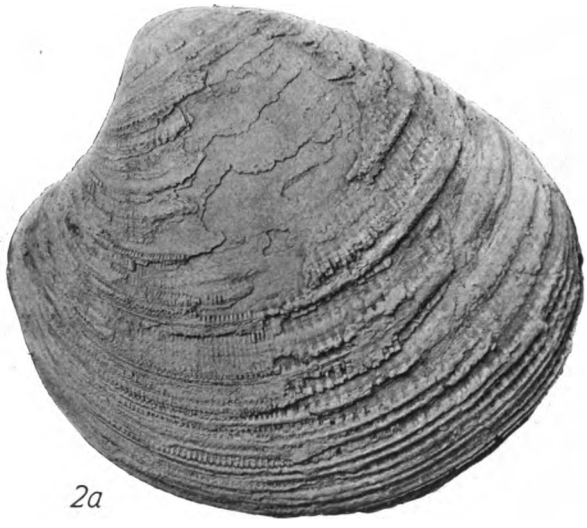

2a

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EXPLANATION OF PLATE 16

Fig. 1. ***Ostrea titan corrugata,*** **n. var. Exterior view of lower valve; Univ. Calif. Coll. Invert. Palae., type specimen no. 11309; locality 2284; Santa Margarita. Approximately three-fifths natural size.**

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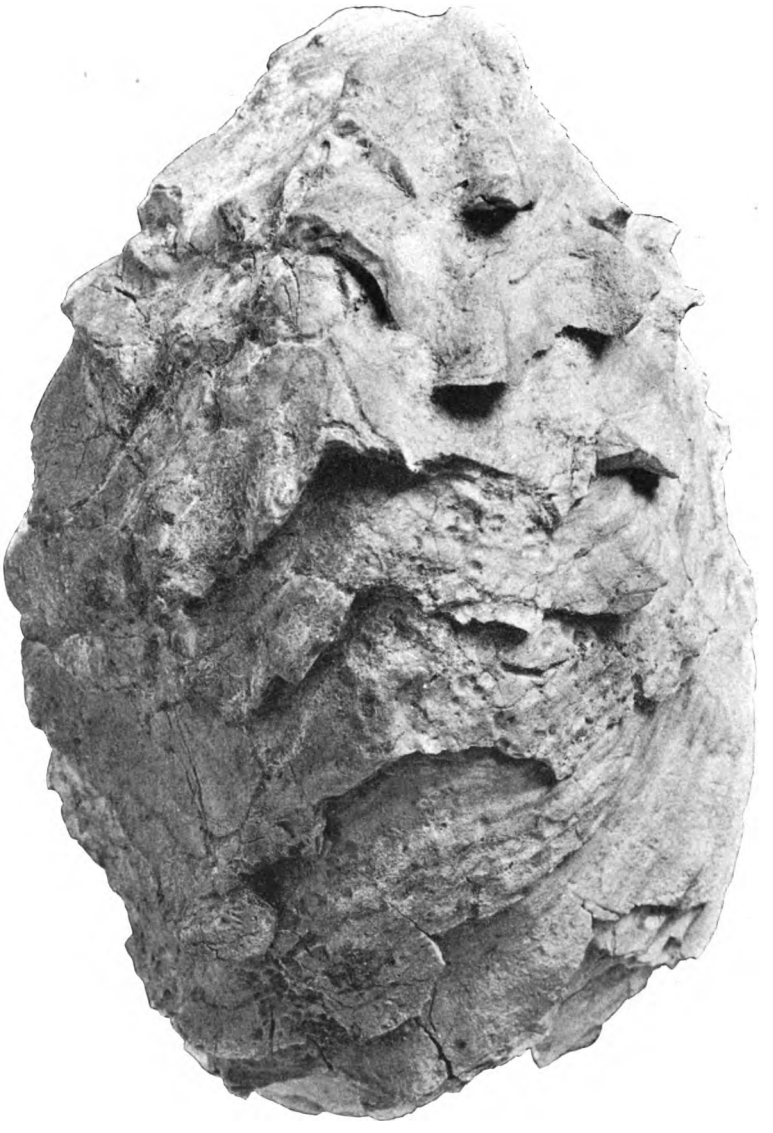

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EXPLANATION OF PLATE 17

Fig. 1. *Ostrea titan corrugata,* n. var. Interior view of lower valve; type specimen no. 11309; from U. C. locality 2284; Santa Margarita. Approximately three-fifths natural size.

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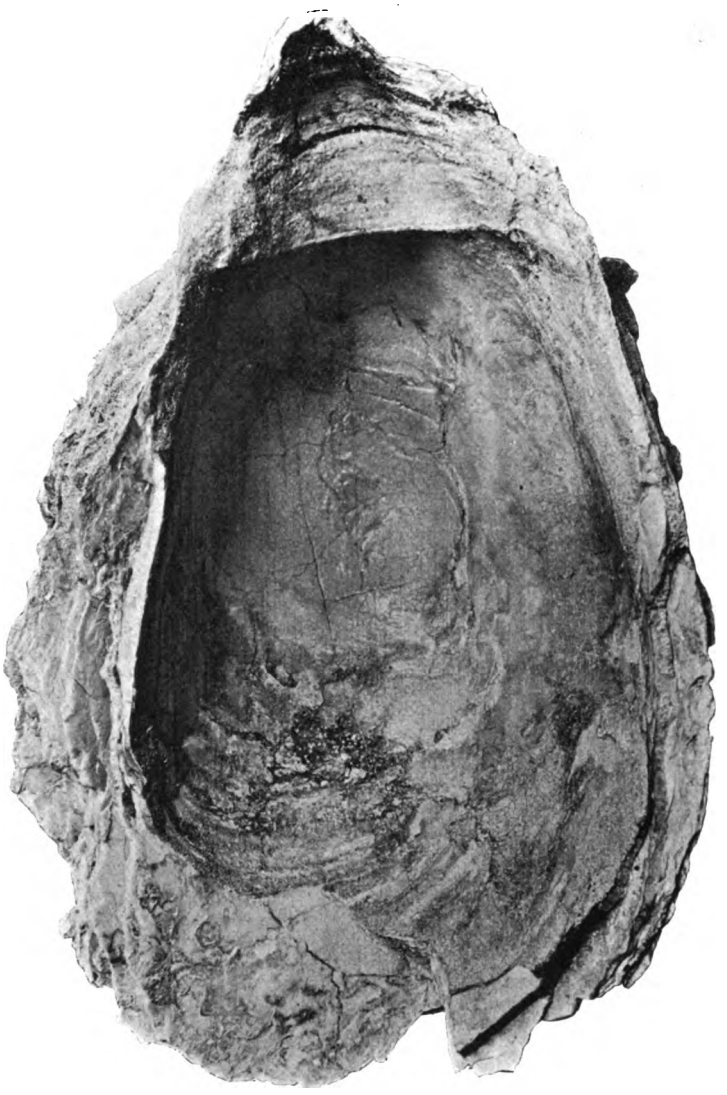

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EXPLANATION OF PLATE 18

All figures approximately natural size.

Fig. 1. *Pecten crassicardo biformatus*, n. var. Exterior view of left valve; Univ. Calif. Coll. Invert. Palae. type specimen no. 11308; locality 3029; Santa Margarita.

Fig. 1*a*. *Pecten crassicardo biformatus*, n. var. View of left valve showing narrow ribs.

Fig. 1*b*. *Pecten crassicardo biformatus*, n. var. Right valve of same specimen as figure 1*a*.

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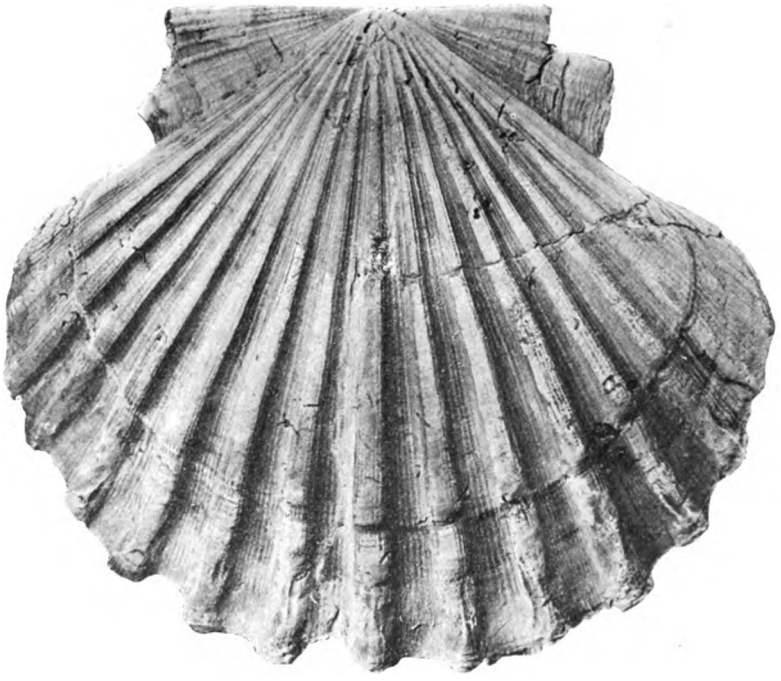

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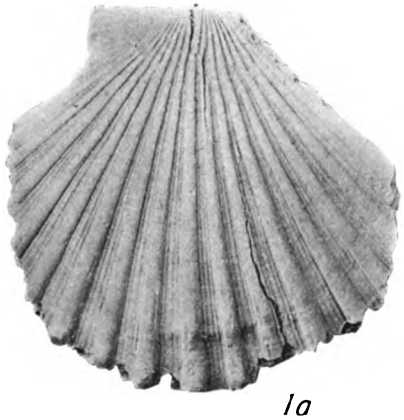

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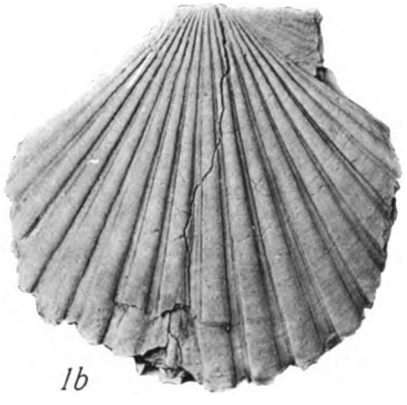

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EXPLANATION OF PLATE 19

All figures approximately natural size.

Fig. 1*a*. *Purpura nanna*, n. sp. Back view of type specimen no. 11315; from U. C. locality 2279; Santa Margarita.

Fig. 1*b*. *Purpura nanna*, n. sp. Mouth view of same specimen as figure 1*a*.

Fig. 2. *Turritella freya*, n. sp. Upright view of type specimen, Univ. Calif. Coll. Invert. Palae. no. 11313. Characteristic of the Santa Margarita.

Fig. 3*a*. *Acanthina* (*Monoceras*) *norna*, n. sp. Mouth view of an excellently preserved specimen; type specimen no. 11314; U. C. locality 2276; Santa Margarita.

Fig. 3*b*. *Acanthina* (*Monoceras*) *norna*, n. sp. Back view of same specimen as figure 3*a*.

Fig. 4. *Pecten crassicardo biformatus*, n. var. Profile of type specimen.

Fig. 5. *Septifer margaritana*, n. sp. Exterior of right valve of type no. 11310; U. C. locality 2276; Santa Margarita.

Fig. 6. *Periploma clarki*, n. sp. Left valve of imperfect type specimen no. 11320; from U. C. locality 2278; Santa Margarita.

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1a

1b

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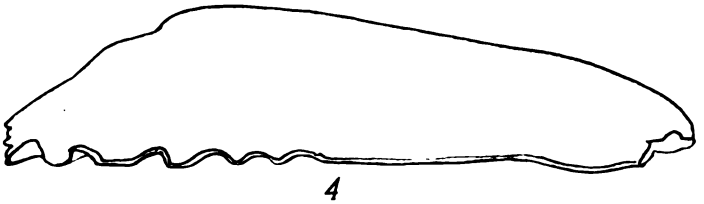
3a

3b



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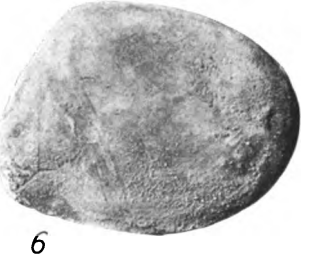

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EXPLANATION OF PLATE 20

All figures approximately natural size.

Fig. 1. *Trophon perelegans*, n. sp. Back view of type specimen no. 11321; Santa Margarita.

Fig. 2. *Trophon perelegans*, n. sp. Mouth view of a small specimen.

Fig. 3. *Trophon perelegans*, n. sp. Back view showing prominent varices.

Fig. 4*a*. *Tegula varistriata*, n. sp. Back view of type specimen no. 11316; characteristic of Santa Margarita.

Fig. 4*b*. *Tegula varistriata*, n. sp. View of aperture and umbilicus of same specimen as figure 4*a*.

Fig. 5. *Turritella margaritana*, n. sp. Upright view of specimen no. 11312; from type section of the Santa Margarita formation.

Fig. 6. *Tegula thea*, n. sp. Back view of type no. 11317; showing shoulder and prominent ribbing.

Fig. 7*a*. *Tegula thea*, n. sp. Back view of a small specimen.

Fig. 7*b*. *Tegula thea*, n. sp. Basal view of same specimen as figure 7*a*.

Fig. 8. *Siphonalia danvillensis* Clark. Rear view of specimen from Santa Margarita, north of Coalinga.

Fig. 9. *Siphonalia danvillensis* Clark. Rear view of type described from San Pablo group.

Fig. 10. *Fusinus fabulator*, n. sp. Upright view of type specimen no. 11319; U. C. locality 3029, Santa Margarita, Tejon Hills.

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MINERALS ASSOCIATED WITH THE CRYSTALLINE LIMESTONE AT CRESTMORE, RIVERSIDE COUNTY, CALIFORNIA

BY
ARTHUR S. EAKLE

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MINERALS ASSOCIATED WITH THE CRYSTALLINE LIMESTONE AT CRESTMORE, RIVERSIDE COUNTY, CALIFORNIA

BY
ARTHUR S. EAKLE

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DESCRIPTION OF THE ROCKS

IGNEOUS INTRUSIVES AND METAMORPHISM

At Crestmore, about eight miles westerly from Riverside, there is an isolated mass of granodiorite with a capping of crystalline limestone which is of exceptional interest because of the many minerals developed in the limestone by contact and hydrothermal metamorphism.

The Riverside Portland Cement Company's plant, situated at the base of the hill, uses both rocks in the manufacture of cement. The extensive quarrying is rapidly destroying the hills, and the different minerals and associations almost daily brought to view are immediately carted to the rock-crushers, so that a vast amount of material of scientific value and many fine specimens are lost.

The writer visited the quarries a few years ago and collected much of the material described here, but no detailed study of the deposits was made and no opportunity has presented itself for a second visit. Specimens have been collected by others and sent to the University, which have been of great help in making the list complete, and special thanks are due Mr. L. J. Childs of Rialto. He has kept in touch with the quarrying and collected minerals that otherwise would have been lost, and these with notes of their occurrence have been given to the writer. About fifty minerals are described in this paper, but these represent only a portion of what probably could be found by daily

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visits. The cement contains the calcined remains of many beautiful, rare, and perhaps new, mineral species.

Hills and Quarries.—The Crestmore limestone forms two hills closely connected by a saddle-ridge. Both hills rest upon a common base of granodiorite somewhat elliptical in contour, with its longer axis trending northeast-southwest. The north is called Sky Blue Hill because of its blue calcite; while the south hill, having pure white marble, has been designated Chino Hill. Sky Blue Hill has a large quarry on its northern side called North Star quarry, a larger one on its eastern side named the Commercial Rock quarry, and between them a third one, the Lone Star quarry, has recently been opened. Chino Hill has one large quarry on its southwest side, and the accompanying view (pl. 21) shows this quarry and the plant of the cement company. The floor of the quarry marks approximately the juncture of the igneous base with the limestone capping.

The limestone forming the capping is a small remnant of a more extensive body of limestone which formerly covered this region. There is a larger mass similar to Crestmore about three miles west, and Slover Mountain near Colton may be another remnant left as a capping upon an intrusive mass.

Intrusive Rocks.—There are three types of igneous intrusives occurring in the hills and all three have been active agents in the metamorphism of the limestone. Granodiorite, quartz-monzonite porphyry and pegmatite are present and intimately associated with the contact phenomena.

The granodiorite is a hornblende-biotite rock with a fairly coarse granitic structure consisting essentially of orthoclase, plagioclase, hornblende, biotite, and quartz. The orthoclase, which appears to constitute the main portion of the rock, is mostly white, and the rock is consequently gray as the prevailing color, but patches of brick-red orthoclase occur, giving the rock a red color. Labradorite and oligoclase are the triclinic feldspars present, but very little albite twinning is seen. The rock is not fresh and all of the feldspars are muddy and opaque. The dark silicates are mostly black hornblende, which is dark green in thin section, and a few plates of biotite. Quartz is much subordinate to the feldspars in amount.

This granodiorite is used by the company as a substitute for clay in the cement. Daily analyses of it are made and three of them will serve to show the relative proportions of the bases.

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SiO_2	60.60%	60.78%	60.30%
Al_2O_3	16.61	16.04	16.03
Fe_2O_3	5.03	4.82	4.19
CaO	7.93	8.22	7.19
MgO	2.08	1.99	2.26
Loss	4.79	4.75	4.42
	97.08	96.60	94.39

The alkalies are not determined in these analyses. Probably some potash and soda have been leached out in the alteration of the feldspars. The granodiorite has its best exposure on Chino Hill and is plainly seen underlying the white limestone. The rock is mined by tunnels into it from the side of the hill below the limestone.

The quartz-monzonite porphyry forms dikes and laccolithic-shaped masses in the limestone of Sky Blue Hill. The rock is very fine-grained, almost felsitic in character, with an ash-gray color. Under the microscope it is essentially a fine granular mixture of quartz, orthoclase and plagioclase with occasional large plates of feldspar and augite. Some pale green and slightly pleochroic hornblende is present, but most of the dark magnesian mineral is augite. It occurs in granular aggregates of a pale bluish-green color and shows no pleochroism. Titanite grains are common in the rock.

This rock forms a wide intrusion into the limestone of Sky Blue Hill, since tunnels run into the hill from the floor of the Commercial Rock quarry penetrate it for several hundred feet. It has been the most active agent in the formation of the metamorphic minerals of this hill.

The pegmatite occurs as intrusive dikes but it is difficult to trace out their boundaries. They appear to be associated more with the metamorphic masses of vesuvianite-garnet rock. The pegmatite consists mainly of white orthoclase and green epidote. Orthoclase occurs in large cleavage masses and is usually pure white in color. The epidote penetrates the feldspathic mass in long slender crystals, most of which are altered to a bronze-brown color. Quartz occurs as smoky granular masses but is not prominent. Zircon, tourmaline, axinite, pyroxene, and a few other minerals are occasionally found as accessories and some minerals have later been developed in the pegmatites by hydrothermal metamorphism.

The Limestone.—Daily analyses are made of the limestone and that from the Chino quarry has the following average compositions:

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SiO_2	4.50%	4.68%	4.26%	5.24%
R_2O_3	1.20	1.24	1.66	1.40
CaO	50.78	50.85	50.00	50.33
MgO	2.50	2.25	2.54	2.60
Loss	40.60	40.36	41.54	40.40
	99.58	99.38	100.00	99.97

Analyses show that about two and one-half per cent of magnesia is the average amount of that oxide in the white limestone or marble, and it is therefore not very dolomitic. Associated with, and merging into this rock are masses of similar white crystalline limestone containing much magnesia, as the mineral brucite, disseminated through it in pisolitic-shaped inclusions. The brucite rock apparently overlies the other limestone, and is seen very prominently on the south end of Chino Hill and near the surface in the Commercial Rock quarry on Sky Blue Hill. It may be a remnant of a separate and distinct bed of magnesian limestone, but the amount of the brucite varies considerably and it has evidently been formed from some other magnesium mineral, whose origin was due to contact metamorphism, and the source of the magnesia might have been in the solutions accompanying such metamorphism.

Metamorphism of the Limestone.—The two hills are utterly dissimilar in the effects of metamorphism. The limestone of Chino Hill was converted into a white marble with very little development of included metamorphic minerals. It does not appear to have suffered successive metamorphism and recrystallization as would be induced by later injections of igneous rock, and the original intrusion of the granodiorite accounts for its simple metamorphism. At the south end of the quarry the rock grades into a brucite-graphite limestone; and the brucite and graphite are so thickly disseminated as to warrant the assumption that the original rock was a highly carbonaceous, magnesia-bearing limestone which, by metamorphism, became converted into a mixture of calcite, periclase, and graphite, the periclase subsequently altering to brucite.

The Sky Blue Hill portion of the limestone capping was subjected to later and more intensified metamorphism by intrusions of the quartz-monzonite and pegmatite, and by the hydrothermal action of the silicated-carbonated solutions accompanying or following these intrusions. Practically all of the minerals developed are products of hydrothermal metamorphism. These solutions also carried phosphates

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and small amounts of metallic sulphides. The beautiful blue calcite occurring only in the north hill is a recrystallization by these solutions, and some of the minerals, like the brucite, apophyllite, okenite, crestmoreite, prehnite, laumontite, etc., have been formed by the action of such solutions on pre-existing minerals.

Zones or bands of contact metamorphic silicates separate the white crystalline marble from the dikes of monzonite and pegmatite, and some of the material is a compact massive and inseparable mixture. Vesuvianite, garnet, and wollastonite are the abundant silicates of Sky Blue Hill. Plate 22 shows three views of the Commercial Rock quarry on this hill.

DESCRIPTION OF THE MINERALS

MINERALS DISSEMINATED IN THE WHITE LIMESTONE OF CHINO HILL

Brucite.—The magnesia hydrate is not disseminated through the limestone as plates or scales but occurs wholly in rounded, pisolitic bodies. The pisolites are generally quite prominent because of their gray, yellow or pink color in contrast to the white calcite. Magnified sections show them to be composed of a congeries of thin, overlapping, curved plates and threads, more or less concentrically arranged, and with a cross-fibered structure. This internal structure indicates great strain and pressure in their formation, and little can be made of them optically. The general interference colors are low, but their compressed, interwoven fibrous structure prevents extinction. An analyses of the pisolites gave:

MgO	67.48%
Fe_2O_3	0.55
H_2O	31.73
	99.76

G = 2.39

Some of the brucite is deeply colored by ferric oxide, which imparts a yellow and red spotted appearance to the white limestone. Near the surface of the hill in the Commercial Rock quarry, where the brucite has been weathered out, the limestone is cellular, with the cavities lined with the yellow or red oxide.

Periclase is assumed to be the original mineral which has changed to brucite by simple hydration. No periclase has been observed and no other mineral occurs in the limestone from which brucite could be derived. The very regular form of the pisolites suggests an

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original isometric crystal with an octahedral shape such as periclase would have had. The internal structure of the brucite clearly indicates that they have formed under great pressure, such as would be produced by expansion within a confined space. In a change from the anhydrous periclase to the hydrous brucite an increase in volume of nearly two and one-half times that of the periclase is necessary under normal conditions, and this great swelling has caused sufficient pressure not only to produce the twisted and fibrous internal structure of the pisolites, but also to curve slightly the twinning planes of the calcite bordering the cavities.

The names *predazzite* and *pencatite* were given to a similar brucite limestone from Predazzo in the classic Monzoni district of Tyrol. Specimens of the predazzite show the same compressed and strained brucites in the white limestone, and they have generally been held to be brucite derived from periclase, and some unaltered periclase has been found. Lanacèk[1] holds from a petrographic study of the predazzite that the pisolites are hydromagnesite rather than brucite. Some of the brucite of the Crestmore limestone is altered to hydromagnesite as a later change but the pisolites are in the main brucite, as shown by the analysis.

Hydromagnesite.—Some of the brucite pisolites have altered by weathering into earthy white material which qualitative tests prove to be the hydrocarbonate of magnesia. It is evidently secondary from brucite and not from any periclase direct.

Chondrodite.—This is the only mineral in the list of which there is no well-authenticated proof of its existence in the quarries. Chondrodite and its characteristic associate, spinel, might be expected among the products of metamorphism in the Commercial Rock quarry, but apparently fluorine was absent, as tests of the spotted limestone which suggest chondrodite failed to show its presence. Specimens of chondrodite have been collected from the Colton limestone. Brucite may form from chondrodite but it much more probable that periclase was the original mineral of the Crestmore rock.

Graphite.—The only place in the quarries where graphite is prominent in the limestone is on the south end of Chino Hill, in close association with the brucite. It is so thickly disseminated through the limestone as small flakes and scales that the rock is of a dark gray color in consequence. The pisolites of brucite are often surrounded by a border of black graphite, probably so oriented by the solutions

[1] Min. u. petr. Mitth., vol. 12, pp. 429, 447, 1892.

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causing the change from periclase to brucite. Graphite was not prominent in the quarries on Sky Blue Hill.

Phlogopite.—A few flakes of brown phlogopite mica have been observed in the white limestone of Chino Hill.

Serpentine.—Very little serpentine has been found on either hill. A few small patches and streaks occur here and there in the white marble of the Chino quarry.

MINERALS IN THE CONTACT ZONES OF SKY BLUE HILL

Blue Calcite.—The blue calcite occurs only in the Commercial Rock quarry. Some of it is intensely blue, especially when freshly exposed, but it fades somewhat to more of a sky-blue color. It does not occur as one large mass of blue calcite, but rather as seams, bands, and patches intimately mixed with the various metamorphic minerals. When the quarry was first opened the blue calcite was very common and was used for road rock and in sugar refining, but very little is now seen. It is one of the contact metamorphic minerals; and in the recrystallization of the carbonate larger rhombohedrons have resulted, some of the cleavage rhombohedrons measuring four to five centimeters in diameter. The cause of the blue color has not been determined, but is believed to be due to minute inclusions of carbonaceous matter. Slight heat completely decolorizes it. This blue calcite forms the matrix for wilkeite, crestmoreite, xanthophyllite, and monticellite, and contains, besides, minute crystals of vesuvianite and diopside. Pale green and pale pink specimens of calcite are occasionally seen, but the prevailing colors are blue and white.

Wollastonite.—The calcium silicate has been most abundantly formed in the limestone, especially on Sky Blue Hill. It forms great masses in the North Star quarry and tons of it can be obtained. Four structural types or habits may be ascribed to the Crestmore wollastonite.

The first has the common reticulated columnar and fibrous structure which is so characteristic of wollastonite. Crystals of this type are long, narrow and much striated, and generally show no end-faces. Masses of this kind of wollastonite have occasionally been encountered in the limestone of the Chino quarry.

The second type is represented by large well-formed crystals having the forms and habit of the usual wollastonite crystals. Glassy white crystals, several centimeters long and more than a centimeter broad,

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occur in direct association with garnet and vesuvianite. They are elongated parallel to the *b*-axis and have one end terminated by fairly good faces. The forms observed on these crystals are:

a (100)	*m* (110)	*v* (101)	*s* ($\bar{2}01$)
c (001)	*x* (120)	*a* ($\bar{1}02$)	*p* (111) new
g (011)	*z* (320)	*t* ($\bar{1}01$)	

The orthopinacoid and base are broad while the domes are very narrow; this gives the crystals an appearance of elongated square prisms. One crystal had a rough face of the front unit pyramid, which is a new form for wollastonite. Figure 1, plate 23, shows this type. The angles obtained with the two-circle goniometer and those calculated are as follows:

	Measured		Calculated	
Forms	ϕ	ρ	ϕ	ρ
c 001	90°00′	5°34′	90°00′	5°30′
a 100	90 00	90 00	90 00	90 00
m 110	43 40	90 00	43 39	90 00
x 120	25 31	90 00	25 30	90 00
z 320	55 10	90 00	55 03	90 00
v 101	90 00	45 21	90 00	45 35
a $\bar{1}02$	90 00	$\bar{1}9$ 36	90 00	$\bar{2}0$ 03
t $\bar{1}01$	90 00	$\bar{3}9$ 13	90 00	$\bar{3}9$ 35
s $\bar{2}01$	90 00	$\bar{6}0$ 03	90 00	$\bar{6}0$ 14
g 011	4 42	46 36	5 39	44 12
p 111	47 10	53 36	46 29	54 34

The third structural type is granular and very unusual for wollastonite. Large masses of snow-white, fine-granular wollastonite occur in the white limestone of the North Star quarry of Sky Blue Hill. The material is loosely coherent and friable; specimens can readily be crushed between the fingers into fine grit and glassy grains. An analysis of this unusual variety gave the composition:

SiO_2	51.77%
Fe_2O_3	2.12
CaO	44.85
Ign.	1.02
	99.76

The general tendency of wollastonite is to crystallize in long columnar forms; when found occurring as a fine granular mass it must mean a peculiar condition of crystallization. Wollastonite usually occurs imbedded in limestone as inclusions, but massive boulders of this granular variety are quarried containing no associated

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calcite. This friable granular variety has every appearance of having been thrown down as crystalline precipitated granules from a cooled saturated solution of the lime silicate. The precipitate was crystalline as every grain is transparent glassy, but the imperfectly formed crystals were not cemented into a compact mass which would have been ordinarily the case in a dense crystallization such as this implies. Presumably this mass, which seems to be a large segregation in the limestone, was formed by rapid crystallization and sudden precipitation from a solution whose temperature was rapidly lowered. This variety is only found on the northern end of the hill and at some distance from the intrusive dikes.

The fourth type consists of distinct crystals which have formed by later silica solutions acting upon the limestone in the vicinity of the pegmatite dikes and on the outer border of the contact zones. Acicular and slender crystals with terminations on one end occur associated with apophyllite and okenite. The crystals are clear and colorless, with bright lustrous faces. By pressure they separate into silky fibers. They possess perfect orthopinacoidal cleavage and have the usual elongation parallel to the *b*-axis. Twenty-three forms were observed, of which twelve were new, as follows:

c (001)	*v* (101)	*g* (011)	*u* ($\bar{1}44$) new
a (100)	*r* (104) new	**p** (744) new	*φ* (122)
l (740) new	*θ* ($\bar{1}04$) new	*o* (344) new	*μ* ($\bar{1}22$)
h (540)	*k* ($\bar{1}03$)	*n* (144) new	*ω* (142) new
q (340)	*a* ($\bar{1}02$)	**b** (744) new	*e* ($\bar{1}42$) new
m (140) new	*t* ($\bar{1}01$)	*i* ($\bar{3}44$) new	

The crystals are slender and consequently the dome faces are narrow and apt to be striated. The base, orthopinacoid and three domes *v a t* are common to all the crystals. One crystal gave readings for narrow but distinct forms corresponding to two new domes (104) and ($\bar{1}04$). The end terminations of the crystals are remarkable. The unit prism (110) and clinoprism (120), which are common forms on wollastonite, are absent, and a new prism (140) predominates; the prisms (540) and (340), known forms but very rare, are common on these crystals. The pyramidal forms are likewise remarkable in showing a similar odd series of symbols and no forms common to the usual crystals of wollastonite. Practically all of the pyramids are new forms. The forms (144) and ($\bar{1}44$) are common on all, with (344) and ($\bar{3}44$) usually present. Two of the crystals have small faces of the forms (744) and ($\bar{7}44$). The forms (544) and ($\bar{5}44$), which

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would complete the two odd series, may also be present, as some approximate readings indicated them, but their occurrence could not be established with absolute certainty. Two very small and poor faces corresponding to the forms (122) and ($\bar{1}22$) and a line face of (011) occur. The two new forms (142) and ($\bar{1}42$) were line faces and gave only approximate measurements.

Another unique fact about these crystals is that for every positive pyramid there is a negative one with like symbols; but the symbols for the rear faces do not correspond to the front ones. It is characteristic that the crystals have three or four prism faces on their ends each representing a different form. Figures 2 and 3, plate 23, show the combinations on some of the crystals. Figure 3 shows the end of the crystals with the rear faces drawn in the left half in reversed position. Figures 4 and 5 are orthographic projections on the clinopinacoid which bring out better the combination of faces.

Only one end of the crystals is terminated, sometimes the right and again the left end. The disposition of the faces indicates a lower grade of symmetry as there is no apparent axis of symmetry, and the crystals could belong to the hemimorphic class of the monoclinic system, or to the triclinic system. The mineral is strongly tribo-luminescent and this physical property is an evidence of a more complex molecular structure. The dome faces on these crystals are identical with those of all wollastonite crystals, but the terminated ends are totally dissimilar.

Forms	Measured ϕ	Measured ρ	Calculated ϕ	Calculated ρ	No. of measurements
c 001	90°00′	5°30′	90°00′	5°30′	25
a 100	90 00	90 00	90 00	90 00	30
l 740	59 03	90 00	59 04	90 00	7
h 540	49 57	90 00	50 01	90 00	8
q 340	35 35	90 00	35 35	90 00	10
m 140	13 25	90 00	13 25	90 00	13
v 101	90 00	45 33	90 00	45 33	22
r 104	90 00	18 35	90 00	18 07	1
θ $\bar{1}04$	90 00	7 41	90 00	7 40	1
k $\bar{1}03$	90 00	11 36	90 00	11 56	1
a $\bar{1}02$	90 00	20 00	90 00	20 00	19
t $\bar{1}01$	90 00	39 33	90 00	39 35	24
g 011	5 12	45 44	5 41	44 12	1
p 744	60 29	62 19	60 31	63 03	3
o 344	38 59	51 16	39 10	51 19	6
n 144	18 33	45 33	18 40	45 37	11
b $\bar{7}44$	$\bar{3}8$ 20	61 41	$\bar{3}7$ 30	60 58	2
i $\bar{3}44$	$\bar{3}1$ 42	48 37	$\bar{3}1$ 38	48 39	7

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Forms	Measured ϕ	Measured ρ	Calculated ϕ	Calculated ρ	No. of measurements
u $\bar{1}44$	$\bar{8}$ 09	44 16	$\bar{7}$ 55	44 19	11
ϕ 122	30 38	47 24	28 57	48 09	1
μ $\bar{1}22$	$\bar{19}$ 02	45 14	$\bar{20}$ 41	45 58	1
ω 142	15 35	62 51	16 05	63 35	1
ϵ $\bar{1}42$	$\bar{11}$ 04	62 57	$\bar{10}$ 41	63 05	1

An analysis of the clear crystals gave:

SiO_2	50.42%
CaO	48.29
MgO	0.60
Fe_2O_3	0.51
Ign.	0.07
	99.89

The optical data were kindly determined by E. S. Larson of the U. S. Geological Survey:

$\alpha = 1.614$; $\beta = 1.629$; $\gamma = 1.631$; $2E = 58° \pm 5°$; $2V = 35° \pm 4°$; Y ∥ fibers; Z ⊥ fibers. Parallel extinction; dispersion perceptible $\rho > v$.

The indices are close to those for pure artificial wollastonite:

$\alpha = 1.616$; $\beta = 1.629$; $\gamma = 1.6321$; $2V = 39°$.

Vesuvianite.—Massive vesuvianite is very common in the metamorphic zones between the monzonite dikes and limestone. It is intimately associated with garnet and diopside. Most of this massive variety has a light yellowish color and shows broad crystal faces. Simple crystals of this yellow color are also common, some of them being very perfect. The blue calcite contains crystals of a darker brown color with brilliant faces and somewhat fused appearance.

Two general habits of the crystals are prominent. The simpler type consists of the doubly terminated pyramid without any modifying faces on the edges, as illustrated in figure 6, plate 24. Occasionally the edges of these are truncated by the second-order pyramid as narrow faces, and a small base may also be present. The sizes of these crystals range from less than one-fourth centimeter to more than six centimeters in width. All of them are of the light yellow color and they are associated with the white crystalline limestone.

The second type consists mainly of the unit bipyramid (111) and second-order prism (100) in about equal development, as shown in figure 7. This type is often modified by very small planes on the edges and on the points of the lateral axes, making a more general combination, as illustrated in figure 8. These crystals have a dark brown

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brilliant surface, with lighter brown interiors, and they occur imbedded in the blue calcite in association with the wilkeite.

The small faces grouped about the ends of the axes are often rounded and give readings which yield improbable symbols, but the ones identified are:

c (001)	*p* (111)	*y* (441)
a (010)	*b* (221)	*s* (131)
m (110)	*t* (331)	*i* (132)
o (011)	*z* (121)	*n* (154) new
		h (285)?

The new form (154) occurs on several of the crystals; the narrow face of (132) rounded into a narrow face which gives a good reflection and corresponds to the symbol (285), but it is not repeated on any other crystal and must be classed as doubtful.

The measured and calculated angles are as follows:

Forms	Measured		Calculated	
	ϕ	ρ	ϕ	ρ
c 001	0°00′	0°00′	0°00′	0°00′
a 010	90 00	0 00	90 00	0 00
m 110	44 50	89 50	45 00	90 00
o 011	0 00	28 20	0 00	28 15
p 111	44 55	37 11	45 00	37 14
b 221	44 56	56 43	45 00	56 40
t 331	45 00	66 19	45 00	66 19
z 121	26 19	49 56	26 34	50 14
s 131	18 30	59 30	18 26	59 32
i 132	18 31	40 23	18 26	40 22
n 154	11 00	34 30	11 18	34 25
h 285	14 30	41 55	14 03	41 34

An analysis of the green vesuvianite by J. B. Wright gave:

SiO_2	36.88%
Al_2O_3	17.61
Fe_2O_3	3.11
FeO	0.46
MnO	1.50
CuO	1.06
CaO	33.27
MgO	4.73
Na_2O	0.34
H_2O	0.61
	99.57

G = 3.36

Garnet.—The cinnamon-colored grossularite is abundant in association with the vesuvianite. Most of it is compact massive and shows

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only an occasional broad face of the dodecahedron. Good crystals also occur and some of the rhombic dodecahedrons measure ten centimeters in diameter. All of those collected are simple dodecahedrons without other forms. Some of the crystals are mere shells of garnet enclosing a center of white calcite.

The massive grossularite was analyzed by J. B. Wright with the following result:

SiO_2	35.53%
Al_2O_3	21.11
Fe_2O_3	3.95
FeO	0.60
CuO	0.70
CaO	36.06
MgO	0.78
Na_2O	0.20
H_2O	1.23
	100.15

G = 3.39

Granular yellow garnet and dark brown massive varieties also occur, apparently in connection with the pegmatite dikes. No analyses of them have been made to determine the particular species.

Diopside.—Associated with garnet in the zone of metamorphic lime silicates, a deep green massive pyroxene occurs, which is probably a diopside of a darker color than the crystals scattered through the calcite. All of the crystals are of a pale yellowish green color and occur as single crystals imbedded in the blue calcite. Most of them are small, only a few millimeters long, but some have been found four centimeters in length. They are all of one general type: short prisms tapering off by a succession of unit pyramids to pointed ends, with or without small basal planes. Figures 9 and 10, plate 24, show this general habit and some of the combinations. The observed forms are:

c (001)	*e* (011)	λ (3̄31)	*d* (131)
a (100)	*z* (021)	*o* (2̄21)	μ (121)
b (010)	*v* (221)	*s* (1̄11)	ι (2̄11)
m (110)	*u* (111)	*t* (1̄12)	*e* (1̄21)
			n (2̄31) new

The new form truncates the edge (110) (1̄21) and occurs on several crystals. The edges have many rounded faces and some of the symbols corresponding to them are given unlettered in the following table of measurements and calculations. They are doubtful forms.

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Forms		Measured		Calculated	
		ϕ	ρ	ϕ	ρ
c	001	90°00′	15°50′	90°00′	15°50′
b	010	0 00	90 00	0 00	90 00
a	100	90 00	90 00	90 00	90 00
m	110	43 34	90 00	43 33	90 00
e	011	25 40	32 58	25 43	33 11
z	021	13 29	50 30	13 32	50 29
u	111	55 04	45 55	55 04	45 50
v	221	49 45	61 40	49 59	61 23
t	$\bar{1}12$	$\bar{1}$ 11	16 51	$\bar{0}$ 44	16 25
s	$\bar{1}11$	$\bar{25}$ 12	33 05	$\bar{25}$ 07	33 04
o	$\bar{2}21$	$\bar{35}$ 32	55 23	$\bar{35}$ 22	55 19
λ	$\bar{3}31$	$\bar{38}$ 17	66 12	$\bar{38}$ 19	66 04
d	131	25 27	62 42	25 31	62 58
μ	121	35 37	55 29	35 36	55 24
π	$\bar{2}31$	$\bar{25}$ 27	62 41	$\bar{25}$ 19	62 55
ι	$\bar{2}11$	$\bar{53}$ 04	45 41	$\bar{55}$ 04	45 50
ϵ	$\bar{1}21$	$\bar{13}$ 53	50 27	$\bar{13}$ 12	50 27
	$\bar{3}52$	$\bar{20}$ 18	57 07	$\bar{20}$ 24	57 36
	$\bar{7}53$	$\bar{45}$ 20	55 09	$\bar{46}$ 11	54 50
	$\bar{8}36$	$\bar{57}$ 49	29 14	$\bar{57}$ 32	28 47
$\bar{14}$.3.10		$\bar{69}$ 57	27 41	$\bar{70}$ 32	27 57
10.12.7		27 01	48 18	27 04	48 37

Xanthophyllite, var. *waluewite.*—The rare brittle-mica xanthophyllite with its associate monticellite from Crestmore has recently been described by the writer,[2] so only the main facts concerning the minerals will be incorporated here. Xanthophyllite was first described and named by Gustave Rose[3] as a wax-yellow mineral in scales and plates, occurring as a constituent of a talc-schist in the Shiskimskaya Mountains in the Urals. Years later the green variety was found and named *waluewite* by Kokscharof.[4] The waluewite or valuevite occurs as a constituent of chlorite schist in the Nicolai-Maximilian mine, near Slatoust in the Urals. These two occurrences are apparently the only ones reported and in both cases the mineral was a schist constituent. The Crestmore waluewite is a product of the contact metamorphism and occurs disseminated through the blue calcite. Masses of the blue calcite speckled with the green waluewite were once very plentiful at the quarry, but none is now seen.

The waluewite occurs in hexagonal-shaped basal plates of a deep grass-green color and vitreous to slight pearly luster. The plates are

[2] Jour. Wash. Acad. Sci., vol. 6, p. 332, 1916.

[3] Pogg. Ann. d. Phys. und Chem., vol. 50, p. 654, 1840. Also in his Reise nach dem Ural, vol. 2, pp. 120, 514, 527, 1842.

[4] Zeitschr. für Kryst. vol. 2, p. 51, 1877. Also in his Mineral d. Russ., vol. 7, p. 346.

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seldom grouped together and they average one-half centimeter broad and four millimeters thick. A few large ones have been found measuring several centimeters in width and thickness. While the basal planes are very brilliant the edges are dull, furrowed and impossible to measure. The thicker crystals show polysynthetic twinning like the micas and extinguish in striated sectors. Thin cleavage plates give a biaxial figure with an apparent optic angle of about twenty degrees. Measurements of the optic angle in sodium light showed a variation from twelve degrees to eighteen degrees. The plane of the optic angle is (100) and the mineral is negative. The refractive indices β and γ in the basal section are practically the same, determined as 1.660.

Several analyses of the waluewite from the Urals have been published and two of them are inserted here for comparison with the Crestmore mineral.

No. 1. Waluewite from Crestmore.
No. 2. Waluewite from Slatoust, Urals. Analyzed by Nikolajef.[5]
No. 3. Waluewite from Slatoust, Urals. Analyzed by Clarke and Schneider.[6]

	1	2	3
SiO_2	16.74%	16.39%	16.85%
TiO_2	.....	.....	tr.
Al_2O_3	42.70	43.40	42.33
Fe_2O_3	2.85	1.57	2.35
FeO	0.41	0.10	0.20
CaO	13.09	13.04	13.30
MgO	20.03	20.38	20.77
Ign.	4.49	4.39	4.60
	100.31	99.77	100.40

G = 3.081

Monticellite.—The blue calcite contains monticellite in small masses and grains scattered through it in close association with the waluewite. One large specimen from the quarry consists of a wide band of massive monticellite separated from the blue calcite by a thin seam of waluewite plates, while the calcite has individual grains and plates, respectively, of the two minerals.

The color of the monticellite is flesh or pale brown and the luster is somewhat greasy. The irregular grains show cleavage faces, but no crystals occur. The mineral is practically infusible and is soluble in acids, forming a gelatinous mass when boiled almost to dryness.

[5] Zeitschr. für Kryst., vol. 9, p. 579, 1885. Abstract.
[6] Amer. Jour. Sci., vol. 43, p. 379, 1892.

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		Gordon Surr, analyst
SiO_2	36.02%	37.46%
FeO	2.82	2.94
CaO	34.36	35.14
MgO	24.74	25.32
Ign.	1.25	.....
	99.19	100.86

G = 3.078

The occurrence of the monticellite and waluewite in close association is interesting because both have crystallized from the same silicate mixture and the waluewite may be viewed as having the composition of monticellite plus the spinel and alumina hydrate molecules. In the discussion of the members of the clintonite group of silicates, Clarke and Schneider make the suggestion that waluewite may have the monticellite molecule in addition to its spinel and olivine molecules although no direct association of the two minerals was then known. Here we have the two crystallized together from a silicate mixture in which the monticellite molecule largely predominated and their crystallizations were practically simultaneous. The composition of the waluewite suggests a mineral mixture of monticellite + olivine + spinel + diaspore in an approximate ratio of 6:1:5:6.

These monticellite and waluewite masses have in all probability been formed by the metamorphism of the brucite-limestone, while the common vesuvianite and diopside, which also occur in the blue calcite, but not associated with the monticellite and waluewite, are evidently products of metamorphism of the ordinary limestone, which has little magnesia. The former two were quite local in their development and were soon exhausted, while the latter are the abundant minerals of the quarry.

Wilkeite.—This interesting lime mineral with the four acid radicals has already been described,[7] so only the essential parts of that description will be given here. Boulders of blue calcite containing the granular pink wilkeite had just been blasted from the face of the quarry on the day the writer visited it, and fortunately specimens were collected of a mineral which would otherwise have gone unnoticed to the crusher.

The wilkeite occurs as small grains and minute hexagonal prisms disseminated through the masses of blue calcite. The mineral is clear

[7] Amer. Jour. Sci., vol. 37, p. 262, 1914.

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and glassy and usually pink but some grains are yellow. The mineral is essentially a calcium phosphate of the apatite group, with much of the phosphate replaced by the silicate, sulphate and carbonate molecules. A summary of the properties of the mineral are: Hexagonal system; $c = 0.730$ approx. Prominent forms $(10\bar{1}0)$ $(11\bar{2}0)$ $(10\bar{1}1)$ and (0001). Imperfect basal cleavage. H = 5. G = 5.234. Color pale pink or yellow. Luster vitreous or greasy. Optically uniaxial, negative. $n = 1.640 \pm .005$; $n - n = .0004$.

Chemical composition is:

SiO_2	9.62%
CaO	54.44
MnO	0.77
P_2O_5	20.85
SO_3	12.28
CO_2	2.10
H_2O	tr.
	100.06

The formula derived from this analysis is:

$$3Ca_3(PO_4)_2 \cdot 3Ca_2SiO_4 \cdot 3CaSO_4 \cdot CaCO_3 \cdot CaO.$$

In order to better show its relation to apatite this may be written:

$$3Ca_3(PO_4)_2 \cdot CaCO_3 + 3Ca_3[(SiO_4)(SO_4)] \cdot CaO.$$

During the past summer more of the wilkeite was observed in the quarry quite near the contact with the monzonite, in crystals several centimeters long, coated with its alteration product. This alteration substance coats the original grains and, in the absence of analyses, was thought to be okenite from its optical characters. There is a possibility that the delicate fibers optically tested are okenite; they cannot be separated from the intermixed wilkeite and their exact composition cannot therefore be determined. Much white secondary material has more recently been found which, as analyses show, does not have the ratio of lime to silica in the proper proportions for okenite. Since it is different from any known silicate, it is described below as a new mineral.

Crestmoreite, a New Mineral.—Since the appearance of the paper on wilkeite, blue calcite has been found in the Commercial Rock quarry containing much soft white material disseminated through it in small bunches, as if it were an alteration, in place, of former crystals and grains included in the carbonate. Some of the blue calcite also contains large individuals of this white material having sharply

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defined crystal boundaries, apparently hexagonal in outline. No wilkeite occurs in it, but it is evidently an altered product, presumably from wilkeite. Analyses show that it is principally a hydrous calcium silicate with some of the silica replaced by the phosphate, sulphate and carbonate molecules. It is a new hydrous silicate of calcium having small amounts of the other oxides in place of the silica and the name *crestmoreite,* after the locality, is proposed for it.

The mineral is compact snow-white with vitreous to dull lustre. H = 3. G = 2.22. It fuses quietly and easily to a slightly vesicular glass. It is very easily soluble in acid, leaving some flocculent silica, while most of the silica goes into solution. Some of the lime can be extracted by boiling water.

The earthy opaque material is not adapted to good optical determinations. It has parallel extinction, positive elongation, low birefringence and $\beta = 1.590 \pm .005$.

Analyses of different samples of the mineral were made, all of them showing phosphates and sulphate in the substance. Some of the CO_2 determined is due to calcite, which penetrates the mineral in thin seams

SiO_2	36.12%	38.30%	34.42%
CaO	42.71	41.20	43.54
P_2O_5	2.38	3.50	3.50
SO_3	2.42	1.25	2.24
CO_2	1.16	.....	.....
Ign.	14.98	15.17	16.24
	99.77	99.42	99.94

These analyses correspond approximately to the formula:

$$20H_2CaSiO_4 \cdot Ca_3(PO_4)_2 \cdot CaSO_4 \cdot CaCO_3 + 10H_2O,$$

and this requires the composition:

SiO_2	35.23%
CaO	41.10
P_2O_5	4.17
SO_3	2.35
CO_2	1.29
H_2O	15.86

If crestmoreite were a clear crystallized mineral like the wilkeite, there would be no doubt that the phosphate, sulphate, and carbonate belonged to it and should be reckoned in its formula; but its earthy structure and composition show that it is changing to a calcium silicate, and it is quite within reason to assume that the three acid radicals are small portions of those in the original wilkeite, which

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have not been entirely leached out, in the hydration and silication of the latter mineral, and therefore have no part in the formula for crestmoreite. An hydrous lime silicate is forming by the alteration of the wilkeite and the ratio of $CaO : SiO_2$ will be as 1 : 1 no matter how much water, or in what way, it enters into the composition.

Crestmoreite can be represented by the simple formula $CaSiO_3 \cdot H_2O$ which requires

SiO_2	44.78%
CaO	41.79
H_2O	13.43

This would make it a simple hydrous metasilicate like a hydrous wollastonite, but it seems more probable that crestmoreite, from the water determinations and derivation from wilkeite, is a hydrous basic orthosilicate.

The following percentages of water were given off at the respective temperatures:

At 102°	1.25%
200	3.27
300	10.27
Red heat	15.11
Blast	16.76

In view of the fact that most of the water is expelled only at the higher temperatures it can be regarded as constitutional, and the above formula can be written H_2CaSiO_4.

Wilkeite is represented by the formula $3Ca_3(PO_4)_2 \cdot 3Ca_2SiO_4 \cdot 3CaSO_4 \cdot CaCO_3 \cdot CaO$, and it can readily be seen how the orthosilicate can increase at the expense of the more soluble phosphate and sulphate through the wilkeite alteration by carbonated and silicated waters. These waters were the heated ascending solutions which brought about some of the later crystallizations, and in the formation of the orthosilicate part of the calcium was replaced by basic hydrogen. The exact formula for crestmoreite depends upon the water and therefore no formula can be advanced that is not open to criticism. As a basic silicate most of the water must be considered as constitutional.

The formula proposed for crestmoreite is $4H_2CaSiO_4 + 2H_2O$. This requires:

	SiO_2		43.32%
	CaO		40.43
Constitutional	H_2O	12.99	16.25
Crystallization	H_2O	3.26	
			100.00

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Riversideite, a New Mineral.—Some of the masses of vesuvianite contain narrow seams of a white fibrous mineral which has similar properties to crestmoreite but with only half as much water, and it does not occur as an alteration of wilkeite, at least not as a direct alteration *in situ*. The mineral occurs in compact fibrous veinlets in the crevices of the massive vesuvianite and has a silky luster resembling satin spar. H = 3. G = 2.64. Fuses at 2 to a white glass. Easily soluble in dilute acid leaving flocculent silica.

The mineral is a fibrous crystallization from the solutions carrying the altered wilkeite or crestmoreite and the analyses show that a lime silicate with a ratio $CaO : SiO_2$ equal to 1 : 1 is, like crestmoreite, the principal constituent with small amounts of the phosphate and sulphate present. In this case also the P_2O_5 and SO_3 are hardly to be considered as belonging to the mineral.

Analyses of the fibers gave:

			Mean
SiO_2	41.29%	41.22%	41.26%
CaO	44.62	44.55	44.58
P_2O_5	.....	3.84	3.84
SO_3	1.84	.....	1.84
H_2O	8.05	8.17	8.11
			99.63

The water determination gave

At 102°	0.80%
150	1.00
250	1.37
Red heat	7.77
Blast	8.05

This water analysis would indicate that it is mainly constitutional, but it is a difficult matter to construct a basic formula for the mineral that is satisfactory. The simplest formula to express the composition of riversideite is $2CaSiO_3 \cdot H_2O$. It may be likened to okenite with its basic hydrogen replaced by calcium:

Okenite	$(H_2Ca)Si_2O_6 \cdot H_2O$
Riversideite	$Ca_2\ Si_2O_6 \cdot H_2O$

The formula $2CaSiO_3 \cdot H_2O$ requires:

SiO_2	48.00%
CaO	44.80
H_2O	7.20

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The analyses of riversideite correspond pretty closely to the formula $15H_2CaSiO_4 \cdot 15CaSiO_3 \cdot CaSO_4 \cdot Ca_3(PO_4)_2 + 5H_2O$, which requires:

SiO_2	42.00%
CaO	44.43
SO_3	1.87
P_2O_5	3.31
H_2O	8.39
	100.00

Disregarding the phosphate and sulphate it appears that the silicate formed is a combination of the basic orthosilicate and the metasilicate, and a formula to express the mineral may be written $6H_2Ca_2Si_2O_7 \cdot H_2O$. This requires:

SiO_2			47.43%
CaO			44.27
Constitutional H_2O	7.11	}	8.30
Crystallization H_2O	1.19	}	
			100.00

The optical properties of riversideite kindly determined for the writer by Mr. E. S. Larsen are:

$\alpha = 1.595 \pm 0.003$, Parallel extinction.
$\gamma = 1.603 \pm 0.003$. Z parallel to fibers.

The name *riversideite,* after the county in which it occurs, is proposed for this new hydrous lime silicate.

The water content of a mineral is always subject to different interpretations; and it is not always possible to differentiate between hydroscopic, crystallization and constitutional water. Both of these new minerals might be interpreted as simple hydro-wollastonites.

Crestmoreite $CaSiO_3 \cdot H_2O$
Riversideite $2CaSiO_3 \cdot H_2O$

Clinochlore.—Small pale green flakes of clinochlore were found in the vesuvianite-masses at the Commercial Rock quarry.

Apatite.—Specimens of greenish blue apatite in granular form associated with green diopside and white wollastonite in white calcite were obtained from the quarry, but it does not appear to be an abundant mineral and no crystals of it have been collected.

Aragonite.—Some of the lime carbonate has subsequently crystallized into the orthorhombic form. It occurs sparingly as fibrous and foliated thin layers interspersed with layers of quartz and calcite.

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MINERALS ASSOCIATED WITH THE INTRUSIVES

Feldspars.—Orthoclase, microcline, oligoclase, and labradorite are present in the quarries as constituents of the igneous rocks. Orthoclase appears to predominate and it forms the larger part of the pegmatites. It occurs red and white. An analysis of the pure white from the pegmatites gave:

SiO_2	64.54%
Al_2O_3	20.86
Fe_2O_3	tr.
CaO	1.86
MgO	tr.
Ign.	0.52
Na_2O	1.18
K_2O	11.85
	100.81

G = 2.54

Pyroxene.—Besides the good crystals of diopside which are scattered through the calcite, there is a deep green pyroxene resembling omphacite, mixed with cinnamon-garnet, which has formed at the contact of the pegmatite and limestone.

Augite.—Occurs as a constituent of the quartz-monzonite porphyry.

Hornblende and Biotite.—Both of these minerals are constituents of the granodiorite, the hornblende greatly predominating. Neither seems to occur in the monzonite or pegmatite.

Titanite.—Granular titanite is rather abundant in the monzonite as a constituent. It occurs pale brown with a marked pleochroism to deeper brown. None of the grains has a crystal boundary.

Zircon.—Minute crystals and larger grains of zircon are scattered through some of the white pegmatite rock. The color of the mineral is clove-brown and some of the crystals show the forms (100), (110), (111), (331).

Epidote.—Deep green epidote occurs as one of the contact minerals of the Commercial Rock quarry. Slender and long crystals and grains are imbedded in some of calcite masses. The mineral is very prominent as a constituent of the pegmatites and is one of the original minerals of the rock. It is present in the pegmatite as long slender crystals having a prominent basal cleavage. The fresh crystals are deep leek-green, but most of them have altered to a bronze-brown and resemble astrophyllite. The elongation of the crystals is parallel to

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the *b*-axis as usual, and they show striated domes with the cleavage base, but no end-faces.

Quartz.—Specimens of compact granular quartz rock found in the talus of the Commercial Rock quarry indicate that seams of quartzite were formed in the crystallized limestone by its metamorphism. It is quite possible that sandstone seams occurred in the original formation and that these have been the source of much of the silica necessary to form such an abundance of silicate minerals. Quartz is a minor constituent of the igneous rocks and occurs in the usual smoky-brown color. Small druses of the mineral are occasionally found, but large crystals are rare.

Tourmaline.—Boron is a characteristic element in the rocks of Southern California and practically all of the pegmatites of that region carry boro-silicates, especially tourmaline. Three of these boro-silicates have been observed in the pegmatites of Sky Blue Hill and a few specimens have been collected, but the writer is without any data concerning them.

The tourmaline is black columnar and occurs sporadic in the pegmatite.

Axinite.—Violet-colored axinite associated with cinnamon-garnet occurs in large fragments in the pegmatite. Bright crystal faces, often striated, occur but crystals are not complete enough to measure. Axinite appears to be common in this particular region, as it is abundant at the Riverside quarry and has been noted in other places in the vicinity. Rogers[8] has described a large crystal from Riverside.

Datolite.—Glassy white datolite with slightly greenish tinge occurs in connection with the pegmatites. The specimens sent to the writer are compact massive.

Scapolite.—Specimens of scapolite were recently collected by Childs. The mineral is in close association with green pyroxene, quartz, feldspar, wollastonite, and grossularite garnet. The color of the scapolite is grayish white, but it contains violet-blue streaks. The variety is probably wernerite.

Apophyllite.—The masses of wollastonite which have formed on the contact between the pegmatites and limestone contain cavities lined with small crystals of apophyllite. The crystals are colorless to white and are usually closely interlocked. Two habits are prominent; one is the common cubo-octahedral type with small faces of the pyramid and the base and second-order prism about equal in size. The other

[8] School of Mines Quar., vol. 33, p. 373, 1912.

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one is the pyramid type with a very small or no base. Only the three forms (001), (100), and (111) occur on the crystals. Some of the crystals have been corroded by solutions and altered into white fibrous okenite.

Okenite.—Radiating botryoidal coatings of okenite occur on the apophyllite evidently as an alteration product. The coatings consist of tufts of fibers and long slender needles. The acicular crystals are too slender for accurate measurements but they appear to be long prisms terminated on their ends by dull domes. Some approximate measurements and an analysis of the mineral were made by William Foshag.

	Measured
(110):(1$\bar{1}$0)	33°40′
(010):(011)	52 00
(011):(0$\bar{1}$1)	75 00

The analysis gave:

		Calculated for okenite $H_2Ca(SiO_3)_2.H_2O$
SiO_2	56.17%	56.60%
CaO	26.10	26.42
H_2O	16.83	16.98
	99.10	100.00

The crystals have parallel extinction and are probably orthorhombic. H = 4–4.5. G = 2.206. Index of refraction = 1.55. Low birefringence, 0.008–0.009. Solution in HCl yielding flaky silica. Fuses easily and gives water in a closed tube. It has formed from apophyllite through the action of carbonated waters, perhaps according to the equation:

$$2H_7KCa_4(SiO_3)_8 + H_2CO_3 = 8H_2Ca(SiO_3)_2 + K_2CO_3.$$

Prehnite.—Two distinct varieties occur filling cavities in the white feldspar of the pegmatite. The first is the common green drusy prehnite. This is intimately associated with laumontite, which may be secondary from it. The second variety is unusual for prehnite. It is light brown to colorless and lacks the drusy surface. In some of the cavities crystals line the walls, but they are so interlocked that single crystals are not separable. One crystal about five millimeters broad and one millimeter thick showed the forms *c* (001), *m* (110), *a* (100), and *o* (061). The base is large and bright but the edge-faces are dull. Most of this brown variety is compact granular with bright basal cleavage planes prominent. It is associated with massive datolite and gray quartz.

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An analysis of this brown variety gave:

SiO_2	44.10%
Al_2O_3	24.20
CaO	25.20
H_2O	5.86
	99.36

Laumontite.—The green prehnite has laumontite coating it in small divergent columnar and fibrous masses. It has the appearance of a secondary alteration of the prehnite and in all probability it is such, although there is no direct evidence to prove it. The mineral is snow-white with vitreous luster. Some of the stouter needles have the characteristic oblique cleavage ends. It fuses readily to a vesicular glass and is easily and completely soluble in HCl, yielding a thick gelatinous mass.

An analysis gave:

SiO_2	53.49%
Al_2O_3	22.01
CaO	10.80
MgO	tr.
H_2O	13.39
	99.69

Opal.—White hyalite coats the walls of some of the cavities in the feldspathic pegmatite, and it coats the apophyllite and okenite to some extent. Under the electric spark it shows strong yellow luminescence, which is an indication that it contains uranium. The amount of material on hand is too small to determine the uranium chemically.

Besides this hyalite opal there is considerable wood opal in some portions of Sky Blue Hill. It is dark brown and black, becoming gray by heating. It shows the wood structure and some of it has small calcite rhombohedrons deposited on it.

SULPHIDE MINERALS

Arsenopyrite, pyrite, galena, sphalerite, greenockite, bornite, chalcopyrite, and tetrahedrite occur in the Commercial Rock quarry, mostly in association with the pegmatite intrusives.

Arsenopyrite has been found in a few small crystals about two millimeters long.

Pyrite is more disseminated than the other sulphides. It occurs in grains, cubes and pyritohedrons, and much of it is altered into brown limonite pseudomorphs.

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Galena occurs in rather large cubes and also massive granular. The specimens collected are associated with garnet dodecahedrons, quartz, sphalerite, pyrite, and chalcopyrite.

Sphalerite is quite black but has the characteristic resinous luster and good cleavage. It occurs in the vesuvianite-garnet masses and some of it contains small coatings of bright yellow greenockite.

The copper minerals, bornite, chalcopyrite, tetrahedrite, and perhaps chalcocite, have been found in grains and small granular masses in the metamorphic zones of silicates.

OXYDATION PRODUCTS

Azurite and malachite occur as thin coatings and as stains in the vesuvianite-garnet mass of rock. Cerussite and anglesite have both been identified as earthy gray coatings on the galena.

The two oxides of iron, limonite and hematite, are common in small earthy masses and as stains. The weathered brucite limestone of the Commercial Rock quarry has much yellow earthy limonite and deep red hematite filling the cellular cavities left by the leached-out brucite. The crystals and grains of pyrite imbedded in the calcite and even in the pyroxene and other silicates have been largely altered into limonite pseudomorphs, probably readily changed by the action of the carbonated waters.

White clay from the orthoclase and chlorite from the epidote, augite, hornblende, and other silicates are natural alteration products.

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PLATE 21

View looking northeast, showing the two hills and the cement plant of the Riverside Portland Cement Company at Crestmore, Riverside County, California. The quarry floor marks the juncture of the limestone and granodiorite.

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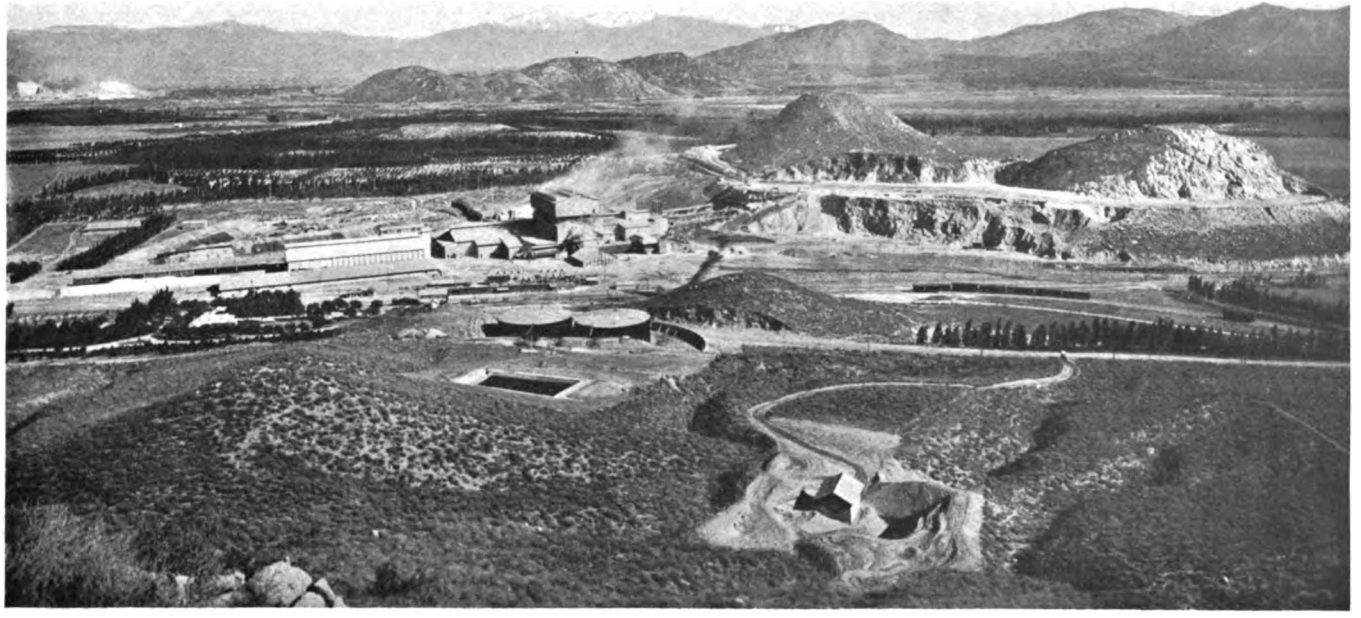

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PLATE 22

Three views showing different portions of the commercial rock quarry on the eastern side of Sky Blue Hill. The quarry face and boulders are mostly mixtures of blue and white calcite, brown vesuvianite and garnet and green diopside.

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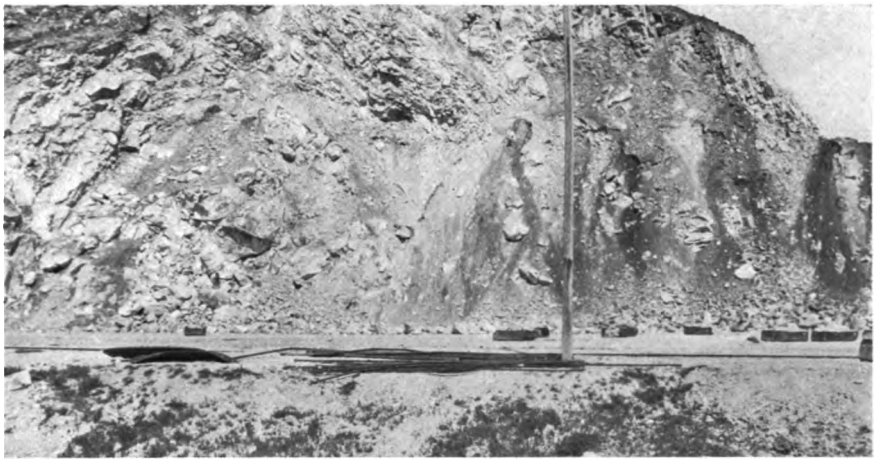

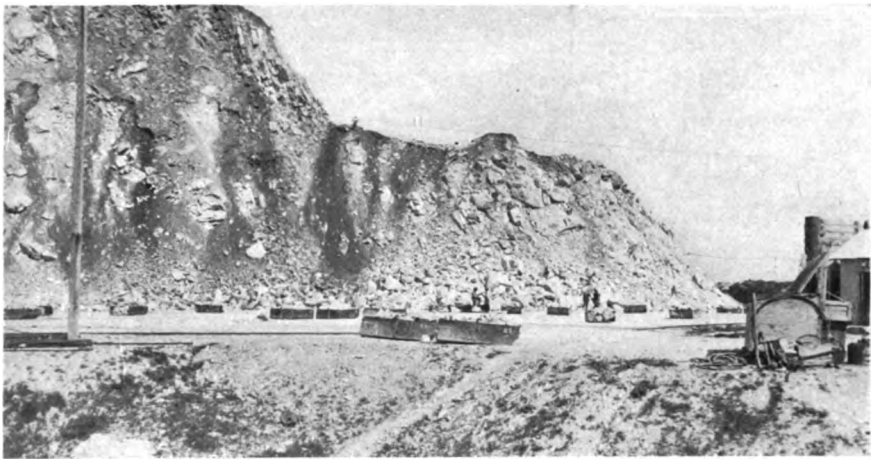

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PLATE 23

Projections of wollastonite crystals, showing the different types and combinations of forms. Figure 1 is the type most common for wollastonite. Figures 2 and 3 are types common at Crestmore. The left half of figure 3 is the rear of the right half drawn to show a center of symmetry only, if the crystal were doubly terminated. Figures 4 and 5 are orthographic projections of the ends, showing better the front and rear faces and the absence of an axis of symmetry.

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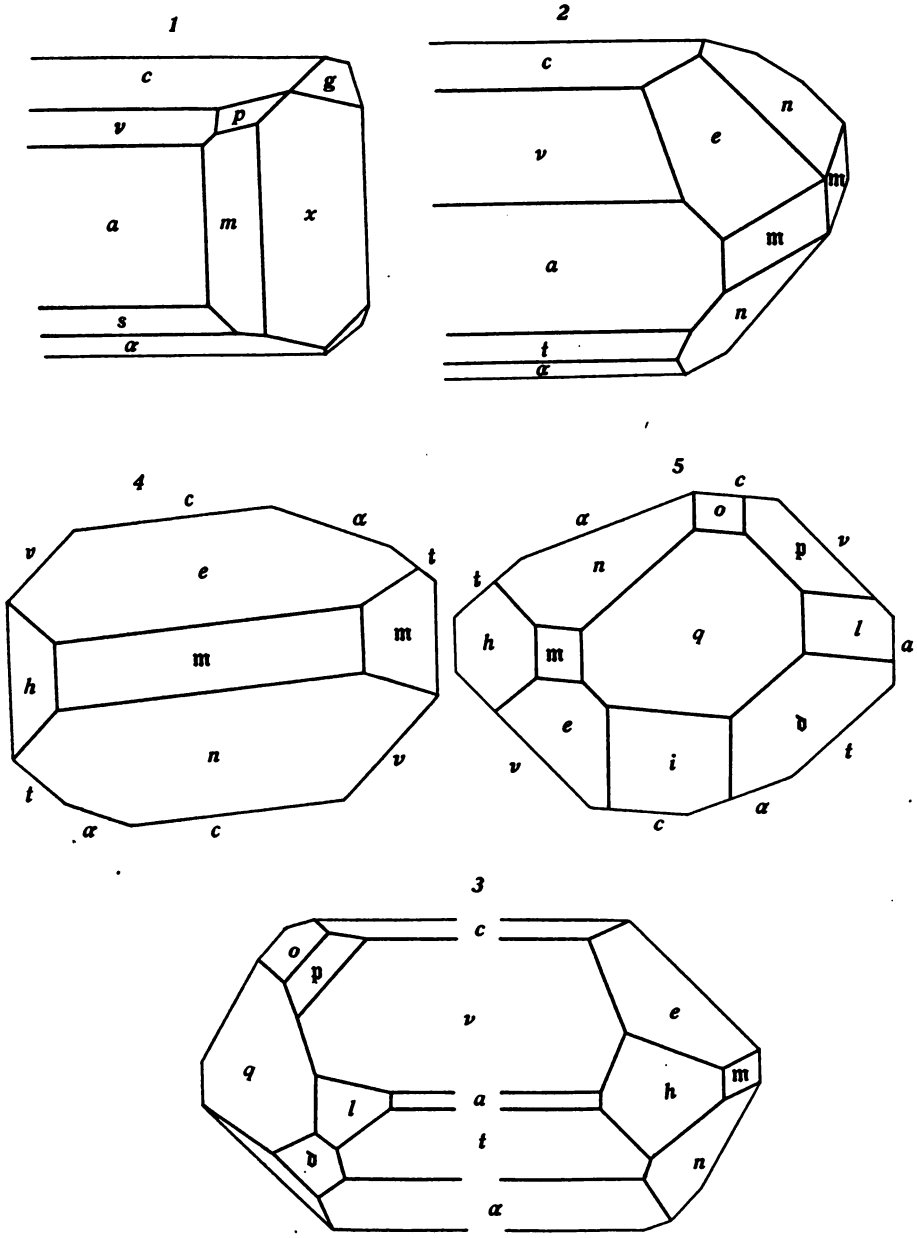

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PLATE 24

Figures 6–8 are projections of vesuvianite crystals showing the general type, but different combinations of forms. Figures 9 and 10 are diopside, showing the characteristic type and combinations.

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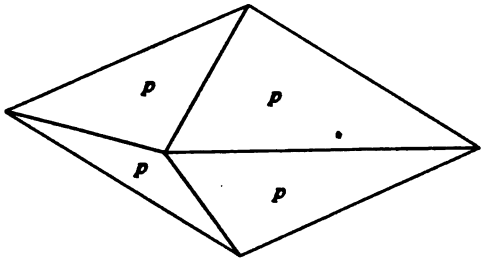

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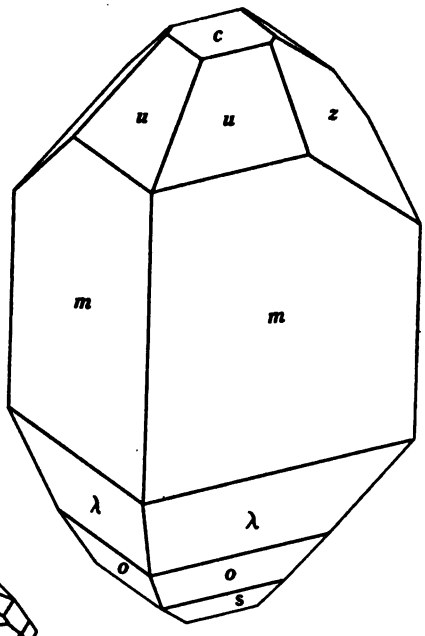

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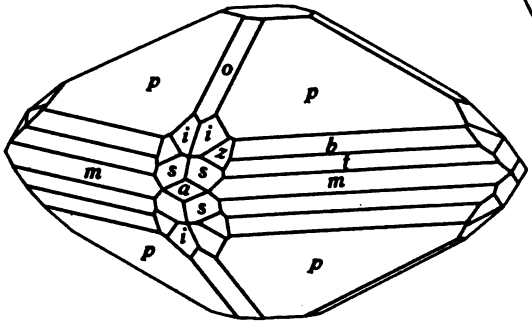

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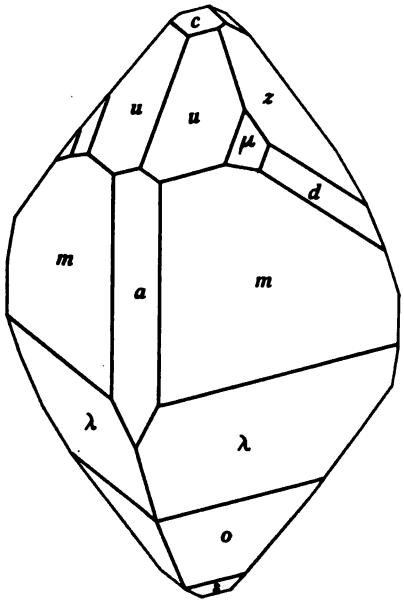

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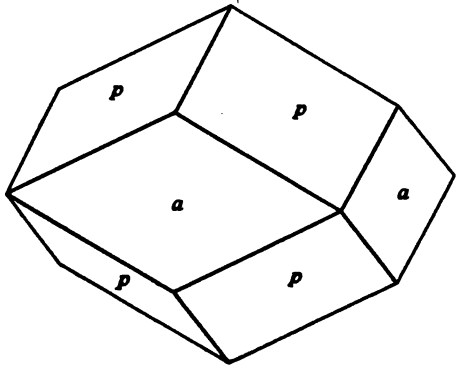

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Vol. 10, No. 20, pp. 361-382, pls. 25-27, 3 text-figures November 8, 1917

THE GEOLOGY AND ORE DEPOSITS OF THE LEONA RHYOLITE

BY
CLIFTON W. CLARK

UNIVERSITY OF CALIFORNIA PRESS
BERKELEY

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CHARACTER AND PURPOSE OF THE WORK

During the fall of 1915 and part of the winter of the year 1916 the writer spent considerable time in the study of the Leona rhyolite as to its extent, its petrographical character, the nature of the surface on which it rests, its structural features, its age and the ore deposits in it.

Professor A. C. Lawson[1] in the San Francisco Folio has given a brief account of the rhyolite and its relations and mapped its distribution. He also devotes a paragraph to the description of the ore deposits. It is the purpose of this paper to give a more detailed description of this very interesting feature of Coast Range geology.[2]

PHYSICAL FEATURES OF THE AREA

The area occupied by the Leona rhyolite is confined to a portion of the front of the Berkeley Hills, which form the steep northeast boundary of the valley of San Francisco Bay. The cities of Berkeley and Oakland are in part located on the foothill slopes, but for the most part they are situated on the alluvial embankments, in part terraced, at the base of the hills. These embankments are now being dissected by the streams which formed them. The front of the hills has a straight northwest-southeast trend and is continuous in its abrupt elevation above the bay plain from San Pablo to the town of Haywards, except for a few cañons which dissect it. A remarkable break, however, occurs at Haywards, where Castro Valley forms a flask-shaped embayment connecting by a narrow gap with the Valley of San Francisco Bay.

The rhyolite, being more resistant to erosion than the surrounding formations, stands out in relief along the front of the hills from its northern end at Berkeley to the vicinity of Haywards. But south of this point it is less prominent and conforms more to the aspect of the topography of the adjacent rocks. The rhyolite is everywhere studded with crystals of pyrite, the oxidation of which has given the characteristic reddish color to the formation. In certain sections where the outcrop of the rhyolite is obscure, the color of the soil derived from it was of material aid in determining its boundary.

[1] U. S. Geol. Surv., San Francisco Folio, no. 193, 1914.

[2] The writer wishes to express his thanks to Professor A. C. Lawson for helpful suggestions and criticism in the preparation of this report, and also to Mr. D. A. McDonell, General Manager of the Leona Chemical Mine, and to Mr. J. M. Conlin, Mine Superintendent, for many courtesies extended during the examination of the mine.

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Pre-Recent Erosional Surface.—In the vicinity of Elmhurst there is evidence of an old erosional surface whose remnants form part of the present topographical surface. The general direction and possible extent of the stream which flowed on this surface is shown by the sketch map in figure 1. It is not known how extensive this former surface may have been, but the evidence used in making the map consists of the presence of stream pebbles composed mostly of Oakland conglomerate and boulders of Chico sandstone. The pebbles found lying loose upon the surface are probably the last trace of the former stream deposits. The small area north of Lake Chabot, mapped as Knoxville, is partially occupied by these pebbles imbedded in alluvium

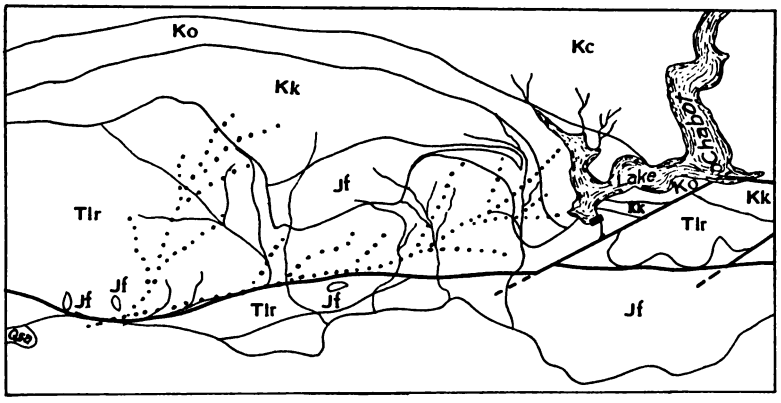

Fig. 1. Sketch, in part, hypothetically drawn, showing the pre-recent stream system and its relation to the present topography. The dotted lines represent the pre-recent stream valleys. The branching full lines represent the present streams. The heavy lines represent faults.

derived from the formations to the east. North of the F. C. Talbot ranch about a mile, along the road leading to the country club, there is a considerable thickness of the old river gravels. Here cross-bedding is well exposed on both sides of the former stream valley. To the south of the road just referred to, in an old stone quarry, the stream gravels are exposed in vertical section. The deposit is about ten feet thick and rests on an uneven eroded surface of the rhyolite. This old stream valley has a course transverse to the present streams. The presence of pebbles on the tops of some of the hills indicates that the former stream system antedates that of the present by a considerable period of geologic time.

The direction of the present stream valleys being at such variance with those of the pre-Recent indicates that the former were superim-

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posed upon the latter. A considerable portion of the country just east of the Haywards fault was covered with detritus and then elevated, the uplift giving rise to the present stream system.

As near as can be judged, at least a branch of the old stream flowed out through Arroyo Viejo Creek during the last stages of its existence. There must have been a large amount of detrital material deposited on the lower hillslopes at the advent of the present erosional cycle. This material has been largely if not all covered by recent alluvium. The former stream system probably represents the period in which the San Antonio formation was deposited. Material similar to that in the San Antonio formation covers a considerable area of the Knoxville just north of Lake Chabot. The material here, however, contains many large boulders, which at some places are imbedded in the finer alluvium; it is the finer alluvium that is similar to the San Antonio.

GEOLOGICAL HISTORY

The portion of the Berkeley Hills here considered is composed of several kinds of rocks, both igneous and sedimentary. The oldest of these, comprising sandstone, conglomerate, quartzite, radiolarian chert, serpentenized peridotite, diabase, ellipsoidal basalt, and glaucophane schist, compose the Franciscan group.[3] Upon this group the lower Cretaceous or Knoxville formation rests unconformably. It is prevailingly a fine-grained arenaceous and carbonaceous shale having a thickness of several hundred feet. As has been pointed out,[4] the shale contains no coarse sand or conglomerate at its base, which would signify a slowly transgressing sea. The lack of this coarse material would seem to indicate that the surface of the Franciscan must have been reduced to low relief and submerged rapidly.

Upon the Knoxville shale rests the Chico or upper Cretaceous. The Oakland conglomerate at the base of the Chico ranges in thickness from 100 feet near Temescal Lake to perhaps 800 or 900 feet east of Leona Heights; near Lake Chabot it reaches a thickness of 1000 to 1200 feet; but it is probably not thicker than 1000 feet near the southern end of the Haywards quadrangle. The upper portion of the Chico is composed of sandstone and shale many thousand feet thick.

The apparent conformity of the Oakland conglomerate and the Knoxville is an interesting point connected with the geologic history

[3] *Op. cit.*, p. 4.
[4] *Op. cit.*, p. 8.

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of the region which is discussed in the text of the San Francisco Folio. The pebbles of the conglomerate are mostly chert, shale, and sandstone, but along with these are numerous boulders of granite and granodiorite. It seems, therefore, that there must have been marked diastrophic movements at the close of the Knoxville epoch, but these movements were not of such a nature as to raise the Knoxville sediments above sea-level.

After erosion which locally removed the Shasta-Chico rocks, the Leona rhyolite was extruded on the surface as a lava flow. From its present disposition it appears that the flow probably followed an erosional valley. The valley must have roughly followed the contact of the Knoxville and the Franciscan. Since the extrusion of the rhyolite there have been several crustal movements.[5] These movements have continued up to recent geologic time, as is shown by the various alluvial deposits, and also by the present streams that in many instances show recent readjustment. The most recent movement has been faulting along a line generally parallel to the Berkeley Hills.

DISTRIBUTION OF THE RHYOLITE

The rhyolite forms a narrow discontinuous belt that extends from Hamilton gulch at Berkeley to a point about five miles southeast of the town of Haywards, a total length of about twenty-two miles. The lava flow has a maximum residual thickness of about 400 to 600 feet, but generally it is much thinner. It presents a rather distinct physiographic feature on the front of the hills due to the steep slopes of its erosional forms. At a number of localities the streams have eroded through the entire thickness of the rhyolite and are now cutting into the older rocks below. Indeed, it seems quite evident that the discontinuous areas of rhyolite are remnants of a former continuous lava flow that was much thicker and wider.

NATURE OF SURFACE UPON WHICH LAVA FLOWED

In some places the rhyolite rests upon the Franciscan, in others upon isolated patches of Knoxville which were not entirely removed from the Franciscan by erosion at the time of its extrusion, so that the lava probably occupied the valley into which it flowed. It was hoped that considerable quantities of stream gravel would be found below

[5] *Op. cit.*, p. 20.

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the rhyolite, but in two or three places only were any gravels found in such a position, and in these places in very limited amounts. However, this does not preclude the possibility that they underlie the rhyolite, because in only a few places is the base of the rhyolite clearly exposed.

The field relations and petrographical character of the rhyolite, which will be discussed later, indicate that the lava probably came from one source and was extruded as a single flow.

AGE OF RHYOLITE

The age of the rhyolite is one of the principal points to be considered, but after much detailed study of its relation to the adjoining formations the time of extrusion has not been narrowly determined. It is certainly post-Chico, and, judging from the degradation of the surface upon which the rhyolite rests, the degree of its alteration, the amount of its erosion, and the extent of post-rhyolite movements, it seems highly probable that it is as old as Pliocene, as has been suggested.[6]

FAULTING

The Berkeley Hills orogenic block[7] is a feature of especial interest in the geology of the Coast Ranges in the San Francisco Bay region. The Haywards fault, which traverses this region nearly parallel to the trend of the rhyolite belt, is comparable to the San Andreas fault because of the similar geomorphic features it has produced. It extends through the area mapped, from Berkeley southeast along the base of the steep slope to the vicinity of Temescal Lake, where it becomes manifest as a rift valley to a point southeast of Leona Heights; here it turns in a more southerly direction and passes through the low front ridge of the hills out under the alluvium. At Arroyo Viejo Creek the rift again returns to the rhyolite area and passing up this creek in a southeasterly direction through a well defined saddle on the F. C. Talbot ranch connects with the oblique fault west of Lake Chabot. The main fault may be offset somewhat by this oblique fault, but from this point it has been tentatively drawn on the map through the several saddles and breaks in the western slope of the hills to the town of Haywards, where it is lost as it passes out under the alluvium.

[6] *Op. cit.*, p. 12.
[7] *Op. cit.*, p. 17.

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Numerous faults of smaller dimensions and probably intimately associated with the Haywards fault have been observed in the area. These minor faults are oblique, parallel, and transverse to the Haywards fault. The northern exposure of rhyolite is cut off at Hamilton gulch by a fault that is transverse to the major movement. This portion of the rhyolite is also faulted against the Chico and Knoxville formations along most of its eastern boundary. At Leona Heights two faults more or less parallel to the Haywards fault and undetermined in extent have aided in producing the geomorphic features of this locality. South of Lake Chabot and again south of Haywards oblique faults extend in a southeasterly direction from the main fault. These oblique faults are probably connected with a main fault, approximately parallel to the Haywards fault, that traverses the country from Lake Chabot southeasterly.

In general the relative movement along the fault plane appears to have been horizontal rather than vertical. At Temescal Lake quite extensive masses of gouge and breccia are exposed at the surface in a railroad cut that traverses the fault for a short distance. It does not seem likely that this amount of gouge was produced by any vertical movement that could have taken place here. It is quite certain that a considerable movement has occurred along the Haywards fault in recent geological time, as is evidenced by the diversion in the direction of the streams that flow transverse to the fault valley. Any statement as to what effect the faulting has had in the geomorphogeny of the region, the number of movements and the geologic epoch in which they occurred would be largely conjectural. But there probably have been several periods of movement along this fault zone in post-rhyolite time, and there is a possibility that the rhyolite may have been extruded at some point on the zone.

GENERAL FEATURES OF THE RHYOLITE

The Leona rhyolite reaches its maximum width of one and one-half miles a little north of the F. C. Talbot ranch, east of Elmhurst. The lava varies in thickness, but reaches a maximum of perhaps 600 feet. Where fresh the rhyolite is light green to bluish in color and varies in texture, being glassy and porphyritic in the northern part, while towards the southern end it is less porphyritic and becomes more felsitic. The rhyolite is everywhere studded with pyrite crystals and contains very few ferromagnesian minerals in the fresh rock. Certain

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facies show amygdaloidal structure, but flow structure is not common, except in certain glassy facies. It is everywhere jointed and fractured and under weathering processes yields a soil which contains numerous angular fragments. The chemical alteration of the pyrite has produced iron oxide that stains the soil to a characteristic brown or red color, so that the regolith of the lava is readily recognized in the field.

PETROGRAPHICAL CHARACTERS

The Leona rhyolite may be divided into four facies, according to texture. The first, which shows the most advanced degree of crystallization, has a felsitic texture and is composed of quartz and feldspar, which only rarely attain phenocrystic development. This will be known as the felsite facies.

The second facies is similar to the above, but consists of phenocrysts of feldspar and quartz set in a dense groundmass that in places is microcryptocrystalline, but is generally cryptocrystalline. This will be designated the felsophyric facies.

The third facies is characterized by well developed quartz and acid plagioclase phenocrysts set in a glassy ground mass and will be designated the vitrophyric facies.

The fourth, or microlitic facies, may well be divided into two varieties, one the glassy and the other the spherulitic. The glassy variety has a hypocrystalline ground mass which grades into a dense glass. The crystalline constituents of the ground mass are mostly quartz, but minute needles of feldspar are sparingly included in the matrix. The spherulitic variety has a glassy ground mass which shows radiolitic areas as distinct from the more dense glass. This grades into devitrified areas which show a cryptocrystalline character. The spherulites are sporadically distributed through the matrix, and also occur sparingly embedded in the phenocrysts.

Felsite Facies.—This is a brownish white rock, composed of feldspar and quartz, having a subconchoidal fracture and a felsitic texture. A very few phenocrysts of oligoclase are present in the ground mass, which is cryptocrystalline and altered. The quartz crystals are frequently rounded by corrosion, but in spots secondary quartz is present in quite large aggregates along fractures. The accessory minerals are pyrite, magnetite, leucoxene, and small needles of apatite.

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Felsophyric Facies.—This is a light green to brown rock containing numerous dense, cloudy, indistinct patches. It has a subconchoidal fracture very similar to that of the rock just described. The ground mass is composed of feldspar and quartz in various irregular aggregates. The white clouded patches appear to be composed of alteration products which are not determinable. In the finer part of the matrix chlorite is present, producing a bluish-green stain in the altered products. The phenocrysts are mostly plagioclase, but a few aggregates of orthoclase and quartz occur in the matrix. The accessory minerals are pyrite, magnetite, zircon, and apatite.

Vitrophyric Facies.—This is a light blue to gray rock having a cryptocrystalline ground mass which appears under the microscope to grade into a hypocrystalline aggregate. Numerous crystals of feldspar, together with some quartz and irregular masses of magnetite, constitute the phenocrysts. A few flakes of biotite partially altered to chlorite are also present in the rock. The small aggregates which make up the matrix are of two kinds: one is principally composed of rounded grains with rare elongated forms, while in the other the elongated crystals of feldspar and quartz form most of the groundmass and the few rounded grains present have been derived mostly by alteration and addition of secondary quartz. The phenocrysts are mostly oligoclase feldspar and quartz, with a few poorly developed crystals of orthoclase. Some of the feldspar phenocrysts have been partially silicified, so that they appear as a dense brownish colored mass that does not always show the original crystalline structure. The accessory minerals are pyrite, magnetite, apatite, and zircon.

Microlitic Facies.—The microlitic facies is composed of two varieties of glassy rock.

1. The first has a cryptocrystalline ground mass which grades into an undeterminable, brownish glass studded with minute elongated feldspars and grains of quartz. In portions of the rock these elongated needles of feldspar are oriented in a single direction, giving rise to a flow structure which is common in this facies of the rhyolite. Feldspar forms the most important phenocrysts, if we exclude certain quite large aggregates of quartz and irregular masses of magnetite in the matrix. Most of the feldspar is altered to kaolin and silica, which form dense clay masses colored dark blue by chlorite. Certain portions of the rock frequently show an intermediate stage between the dense glassy base and the microlitic structure.

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2. The second variety is of a light gray, green or bluish color, except where stained with iron oxide; it has a subconchoidal fracture, appears massive, and is very hard. Under the microscope the ground mass appears to be cryptocrystalline or microlitic, and in it are scattered numerous groups or aggregates of spherulites, which are of two kinds: those that are in circular groups imbedded in a dense brown glass, and those that are sporadically scattered through the ground mass, and are also present in the altered phenocrysts. The former are microscopic in size, spherical in shape and show no distinct radiating fibers, but give a black cross between the crossed nicols, as shown in plate 25, figure A. According to Iddings,[8] the number of plates of feldspar composing such spherulites increases to such an extent that the outline of each individual plate is lost; and when no distinct trace of any single fiber can be seen the ideal spherulite is produced. The second kind of spherulite is composed of fibers and plates, whose outlines can be seen under the microscope. In some cases they appear to radiate from a small grain at the center, probably quartz. These spherulites do not show a black cross between the crossed nicols. They appear to be as numerous in the altered phenocrysts as in the glassy matrix. According to Iddings,[9] spherulites of this type are composed of radiating plates or prismoid crystals. An example is shown in plate 25, figure B. This variety of the microlitic facies does not show the flow lines as distinctly as that first described, but both kinds of spherulites are present in most of the sections examined of this facies.

DISTRIBUTION OF THE DIFFERENT FACIES

The four types of rhyolite have a rather definite distribution along the extent of the outcrop. The rock grades from a more glassy facies at the northern end of the belt to a more crystalline facies at the southern end. Both varieties of the glassy facies were obtained in that portion of the belt between Berkeley and Leona Heights. At Leona Heights some of the specimens collected were glassy, while others showed a distinct porphyritic character. From the vicinity of Leona Heights to Lake Chabot the rock is predominately porphyritic in texture. South of Lake Chabot to the town of Haywards the felsophyric facies predominates; that is, the ground mass in the rhyolite becomes much more granular and the glassy material is not so common in the

[8] Iddings, J. P., Igneous Rocks, vol. 1, p. 229, 1909.
[9] *Op. cit.*, p. 229.

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matrix. In this facies the phenocrysts are much less common, and those present are of small dimension. The rhyolite southeast of Haywards has been classed as felsite. In this portion of the outcrop alteration has been so intense that fresh rock is very hard to obtain. However, the rock shows a rather uniform felsitic texture, with a feeble development of small phenocrysts.

SUMMARY OF THE MICROSCOPIC STUDY

The petrographical study of the rhyolite shows that it may be divided into four facies largely based upon textural differences. The series includes a range of facies from those which are mostly glassy to those which are holocrystalline containing only a few small phenocrysts.

The rock is comparatively simple and rather uniform in composition. Orthoclase, plagioclase, mostly oligoclase, and quartz are the essential constituents of the original rock. The accessory minerals are pyrite, magnetite, apatite, zircon, and leucoxene. Only the first three mentioned are in abundance. This study seems to support field evidence that the different facies are probably products of a single lava flow and came from a common source.

CHEMICAL CHARACTERS

The chemical composition as given in three different analyses is as follows:[10]

	(1)	(2)	(3)
SiO_2	71.00	72.12	71.60
TiO_2	.....	.17	.12
Al_2O_3	12.70	11.49	11.93
Fe_2O_3	.66	2.77	3.00
FeO	2.44	2.30	3.40
MnO	.....	.10	.09
CaO	.90	.94	.52
BaO	.....	Trace	.....
MgO	1.39	.85	1.33
Na_2O	6.45	5.28	4.62
K_2O	2.99	.86	1.90
P_2O_5	.....	.88	.62
SO_3	.....	.....	.08
CO_2	.....	1.15	.38
FeS_2	.....	.03	.....
Cl	.....	Trace	.....
H_2O (at 110° C.)	.28	.06	.07
Ignition	1.56	.96	.55
	100.37	99.96	100.21

(1) Analyzed by C. P. Richmond in the laboratory at the University of California.
(2) and (3) Analyzed by G. E. Colby in the laboratory at the University of California.

[10] U. S. Geol. Survey., San Francisco Folio, no. 193, p. 12, 1914.

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The analyses cannot be considered to represent the composition of the original rock, for all of the specimens collected have suffered partial alteration. The high content of silica and low percentage of lime, with a rather high content of Na to that of K, indicates that the rock is a soda rhyolite. The rather constant percentage of Al_2O_3 in the three analyses given above is of interest because in all the sections studied of this rock free kaolin was observed as an alteration product.

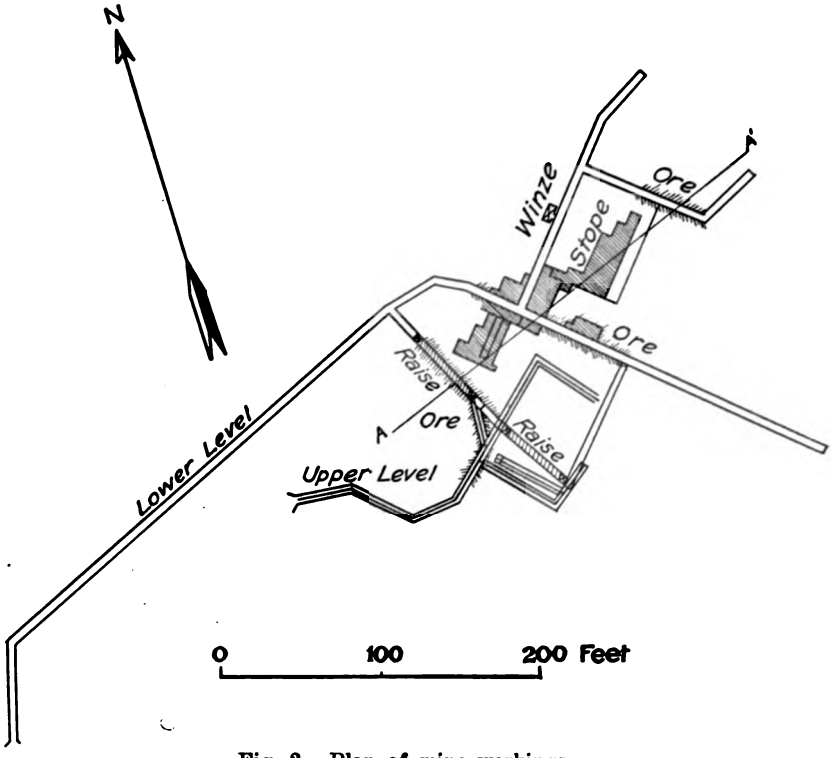

Fig. 2. Plan of mine workings.

PYRITE DEPOSIT

Location.—Near Leona Heights, east of Oakland, deposits of pyrite occur in the rhyolite which have been mined for a number of years. At the present time two mines are in operation, one having just recently started. One of these mines, once known as the Leona Heights Mine, was described in 1911.[11] The larger mine, operated by the Leona Chemical Company, is the principal source of information contained in this report.

[11] Mace, Clement H., Min. and Eng. World, vol. 35, p. 1320, 1911.

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Underground Development.—The mine of the Leona Chemical Company is opened by two tunnels entering the hill at two levels, 75 feet apart. The approximate position of the tunnels and of the ore body is shown in figures 2 and 3. The ore observed in the workings is in a potato-shaped mass in the mineralized zone, and is of two kinds. The soft ore is nearly everywhere surrounded by gouge ranging from a few inches to two or three feet in thickness. The hard ore, which forms but a small part of the deposit, is highly silicified, contains more chalcopyrite, and is not bounded by fault gouge.

Most of the ore has been taken from the lower level, although quite important bodies extend above the upper tunnel. A winze was put down 40 feet from the north crosscut on the lower level, and it is said

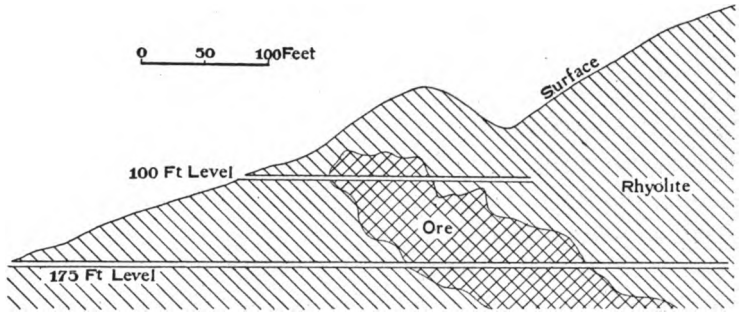

Fig. 3. Diagrammatic vertical section of ore body along line A–A′.

that ore was encountered all the way down. A raise was driven from the southeast part of the lower tunnel and ore was struck 20 feet above the level, so that it is evident that the ore body dips into the hill, as is shown in the vertical section.

Occurrence.—The ore is confined to the rhyolite and is not in contact with any other rocks so far as is known, but the deposit described by Mace[12] rests on a shale, probably Knoxville, and not a part of the Franciscan, as he suggests. The pyrite is massive and has fragments of country rock included in it. The ore occurs in a fracture zone in the rhyolite, which is jointed and faulted so that considerable quantities of gouge and small displacements may be seen nearly everywhere in the mine; but there is abundant evidence of more intense fracturing and differential movement that has probably caused the localization of the ore bodies.

At nearly every place in the mine where the margin of the ore is

[12] *Op. cit.*, p. 1320.

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exposed the latter is surrounded by a considerable thickness of gouge composed mostly of kaolin and silica partly replaced by pyrite, an illustration of which is shown in plate 26, figure A. The pyrite commonly grades out from the solid ore through the gouge into the wall rock. In some of the most recent workings a hard type of pyrite has been encountered. Although a small mass of this was struck on the lower level, yet the main body was encountered in a raise from this level. This ore contains a considerable quantity of chalcopyrite. The wall rock adjacent to the ore, and into which it grades, is highly silicified and contains small masses of kaolin. It is more thoroughly crystalline, contains a larger percentage of silica, and is much harder than the other type of pyrite. An illustration of this is shown in plate 26, figure B.

Mineralogy.—The minerals derived from the ore according to Schaller[13] are pyrite, chalcopyrite, copper, melanterite, pisanite, chalcanthite, copiapite, epsomite, hematite, limonite, alunogen (?) and boothite. Besides these the writer has observed chalcocite, bornite, and sphalerite in the ore. The pyrite, however, is the only mineral of economic importance and is used to make sulphuric acid.

Metallographic Study of the Ore.—A number of polished surfaces of the pyrite and of the country rock partially altered to pyrite were studied for the purpose of determining the nature of the metasomatic replacement of the rock by the pyrite and associated sulphides. The two types of pyrite already described show a rather marked difference under the metallographic microscope. The crystals of pyrite in the massive or softer ore are not so well cemented together as are the crystals in the harder type, but appear to be more dense and do not contain as much silica. The mineral has a very irregular pitted surface even after careful polishing, and the whole mass is made up of materials varying in density and hardness and also in the degree of cementation of their constituent parts; consequently no good polished surfaces were obtained. Quite often the outlines of large cubes can be seen, but the pyrite constituting these is in very small crystals and may often be picked out with a needle point. Between these large cubical or irregular masses are distributed smaller patches of pyrite, which are generally hard and can be polished. The remaining area is mostly occupied by very small crystals of pyrite mixed with dark silica. It is very probable that this portion of the ore is still in the making; that is, the pyrite has not replaced all of the rock and some of the more resistant materials are still present as a part of the ore.

[13] Univ. Calif. Publ., Bull. Dept. Geol., vol. 3, no. 7, 1903.

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A second generation of pyrite occurs in a very fine, dense deposit in fracture zones in the first generation. With this later pyrite small stringers of chalcopyrite and sphalerite have been deposited contemporaneously.

The second type of pyrite is much harder in character than the type just described, for it contains a considerable amount of silica between the partially developed crystals and between the irregular masses of the ore. Where the crystals are not in contact they are very securely cemented together by a siliceous matrix. Chalcopyrite of two generations appears in this pyrite; some was deposited with the pyrite and some has since been deposited along cracks, partially replacing the pyrite. Sphalerite and bornite are associated with the second generation of chalcopyrite and were probably deposited at the same time. One or two small stringers of chalcocite were observed along very small fractures in the chalcopyrite.

The highly silicified country rock, containing a large number of irregular masses of pyrite of varying size, seems to represent the first stages of metasomatic replacement in the formation of the ore body.

Genesis of the Ore.—Two general hypotheses may be advanced to account for the origin of the pyrite at Leona Heights:

(1) It was deposited as a metasomatic replacement in the rhyolite by magmatic waters along a fracture zone.

(2) It was formed as a metasomatic replacement in the rhyolite by cold descending solutions carrying iron sulphates derived from the oxidation of the disseminated pyrite.

The first of these processes does not seem to have had any part in the production of the ore body, for if the sulphides were deposited by magmatic waters there would be evidence in the mine of hydrothermal alteration, together with minerals that are thought to be the products of ascending thermal solutions; but nowhere in the mine has such alteration been observed or such minerals found.

The second hypothesis appears to account for the ore at Leona Heights. Small deposits of pyrite formed by meteoric waters at ordinary temperature have been reported from numerous localities, the iron in many cases being supposed to have been derived from the ferromagnesian minerals, and the deposition of the pyrite in the present instance has been probably brought about by similar processes.

It is thought that the ore at Leona Heights was formed in a manner analogous to that known as the process of secondary sulphide enrichment. The disseminated pyrite when oxidized at the surface formed

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iron sulphate and sulphuric acid. These products having been carried down by descending meteoric waters to the ground water-level, or the zone of reduction, lost the free acid and the salt was reduced to pyrite.

According to Emmons,[14] pyrite oxidizes as follows:

$$FeS_2 + 7O + H_2O = FeSO_4 + H_2SO_4$$
$$6\,FeSO_4 + 3O + 3\,H_2O = 2\,Fe_2(SO_4)_3 + 2\,Fe(OH)_3$$

Ferric sulphate then breaks down, forming ferric hydroxide and sulphuric acid. However, this last step is not always completed in the zone of oxidation, for the analysis of mine waters commonly reveals the presence of ferric and ferrous sulphates below the zone of oxidation.

It seems probable that most of the iron sulphate is reduced to sulphide before the ferric hydroxide stage is reached in the process of oxidation, or else limonite would be produced, as pointed out by Emmons.[15] He gives the following equations for this last process:

$$Fe_2(SO_4)_3 + 6\,H_2O = 2\,Fe(OH)_3 + 3\,H_2SO_4$$
$$4\,Fe(OH)_3 = 2\,Fe_2O_3 + 6\,H_2O = 2\,Fe_2O_3.3\,H_2O + 3\,H_2O$$

It seems, then, that whatever the stage in the process of oxidation sulphuric acid is produced.

According to the experiments of Allen, Crenshaw, Johnson, and Larsen,[16] pyrite will not form in the presence of a strong acid solution, but weak acid or neutral solutions are necessary for the formation of pyrite at ordinary temperatures. They also conclude from their experiments that neutral solutions and high temperatures favor the formation of pyrite, while acid solutions and low temperatures favor the formation of marcasite.

In the light of these facts it seems necessary to explain a method of neutralization of the acid formed in the oxidation of the pyrite near the surface. When the rhyolite alters it forms kaolin and silica. Both of these minerals are very abundant in the altered rock. The experiments of Whitman[17] suggest the explanation of at least part of the neutralization of the free acid in the sulphate solution. They show that basic aluminum sulphate is formed and that pyrite is precipitated as a result of the reducing qualities of kaolin. It is a well

[14] Emmons, W. H., The Enrichment of Sulphide Ores, U. S. Geol. Surv., Bull. no. 529, p. 48, 1913.

[15] *Op. cit.*

[16] Am. Jour. Sci., ser. 4, vol. 33, p. 169, 1912.

[17] Whitman, A. R., Vadose synthesis of pyrite, Econ. Geol., vol. 8, p. 455, 1913.

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known fact that crystals of pyrite, according to Ransome,[18] are found in and associated with kaolin, for kaolin is very abundant in the oxidized zone at Goldfield, and is also found in the sulphide zone, associated with quartz, alunite, and crystals of pyrite. He also states[19] that pyrite forms a considerable part of the altered rocks, particularly the dacites and latites that have been altered to alunite and kaolin rock. In the Butte district Weed[20] reports pyrite, sericite, and quartz as the chief minerals in the altered zones. Mr. Lindgren[21] gives pyrite as a mineral formed in the zone of secondary sulphide enrichment by meteoric waters.

The Relation of Fracturing to the Ore Deposit.—The rhyolite in the vicinity of the ore deposit is intensely fractured, as shown in the mine workings. Along most of the fracture planes the fact of movement is shown by slickensides or gouge. The intensity of the movement along fractures has been doubtless due to the larger faults that traverse this region. The major fault traverses the valley to the west, while a minor fault, as shown on the geologic map, extends through the hill near the pyrite deposit. The development of this complex fracture zone has facilitated the passage of the meteoric waters through the acid porphyry in such a way as to cause the localization of the ore at this point. It is also possible that the two types of pyrite are the products of a continuous period of mineralization interrupted by faulting movement.

The Reducing Effect of the Rhyolite.—The oxygenated meteoric waters descending through the intensely fractured acid porphyry would react on the feldspars in the wall rock, producing sulphates, kaolin, and silica, and it seems probable that by the time these descending solutions had traveled vertically and probably for some distance horizontally through the rhyolite, which was then much thicker and wider than at present, they would have become neutral, or even slightly alkaline. According to Emmons,[22] acid solutions may become neutral, and even alkaline, in a relatively short distance from the surface. He says: "There is considerable evidence that acidity decreases below the water-level. Analysis of two samples of water taken from a column of water in the Callaway shaft, Ducktown, Tennessee, indicate a decrease in acidity of more than 50 per cent within a ver-

[18] Prof. Paper, U. S. Geol. Surv., no. 66, p. 127, 1909.
[19] *Ibid.*, p. 113.
[20] Prof. Paper, U. S. Geol. Surv., no. 74, p. 90, 1912.
[21] Economic Geology, vol. 2, p. 105, 1907.
[22] *Op. cit.*, p. 89, 1913.

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tical distance downward of 37 feet. Some of the analyses from the Capote mine, Cananea, Mexico, show also a neutralization of acid at comparatively shallow depth. The geologic data are comparatively in harmony with this conclusion, for there is abundant evidence that descending acid waters attack alkaline or alkaline-earth silicates and alkaline-earth carbonates; acid reacting with feldspars or sericite forms kaolin, and these reactions are attended by the solution of alkalies or alkaline-earths as sulphates."

It is probable that the sulphate solutions upon reaching the ground water-level, or the reducing zone, lost free acid and became neutral. The sulphate was then reduced to the sulphide and the pyrite-ore body formed as a metasomatic replacement in the rhyolite.

From the character and disposition of the ore deposits at Leona Heights it seems probable that the rhyolite at this place is underlain by the Knoxville shale; indeed, from the exposures of this shale near by, as shown by the geologic map, it may be safely inferred that the shale lies at a comparatively short distance below the present workings in the ore body. The ore body described by Mace[23] rests on a carbonaceous shale, and he concludes that organic matter from the shale was taken into the underground circulation and produced a local reducing water table. The ore, as far as has been exploited, appears to have a downward trend or pitch towards the northeast, so that it may extend to the shale. The shale may have supplied reducing agents in the form of carbonaceous matter and H_2S to the ground water. The downward percolating water contained in solution the metallic salts. The surface of the underground water was probably near the top of the shale formation and the water was supplied with carbonaceous matter and H_2S derived from the shale. When the two waters met at the water table the ferrous sulphate was completely reduced to pyrite. If this be so, the influence of the shale on the chemical condition of the ground water may have been a potent factor in the localization of the pyrite deposit. Much light will be thrown on this point when the lower limit of the ore is determined, and the probability of shale lying not far below the present mine workings should be considered in plans for exploitation at lower levels.

[23] *Op. cit.*, p. 1320.

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SUMMARY

The Leona Rhyolite occupies a narrow belt along the front of the Berkeley Hills from Hamilton Gulch at Berkeley to a point about five miles southeast of Haywards.

It comprises a lava flow that probably followed an erosional valley along the contact of the Knoxville shale and the Franciscan. The rock is very much fractured and has undergone alteration by surface agencies. The rhyolite contains pyrite as an original mineral, the oxidation of which has colored the surface reddish brown.

The rhyolite is probably Pliocene or older, and has been quite extensively faulted in post-Pliocene time, some of the movements occurring in very recent time.

The petrographical study of the rhyolite shows that it may be divided into four distinct facies, based principally on texture. It shows a gradual gradation from glassy and spherulitic through porphyritic to felsitic facies. This supports the field evidence that the rock probably came from a common source and represents a single flow.

The chemical analyses show that the rock is a soda rhyolite.

East of Oakland, near Leona Heights, there are considerable masses of potato-shaped bodies of pyrite in the rhyolite.

The metallographic microscope shows that there are two types of pyrite: one soft and massive, and another highly silicified and very hard. The ore contains chalcopyrite in very small quantities, which was mostly deposited contemporaneously with the pyrite. Traces of secondary chalcocite have also been detected.

The ore deposit was formed as a metasomatic replacement in the rhyolite by descending meteoric waters. The ore body is in a fractured zone determined by a fault in the rhyolite which allowed free passage of meteoric water. The reducing condition of the ground water may have been induced in part by carbonaceous matter from the Knoxville shale that probably underlies the ore body at Leona Heights.

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EXPLANATION OF PLATE 25

Fig. A. Showing the ideal type of spherulite. The number of plates of feldspar that make up the spherulites are so small and are in such large numbers that the outline of each individual plate is not visible. × 230.

Fig. B. Showing the spherulites in the ground-mass and in the altered remnants of phenocrysts. The prismoid crystals that make up the spherulite are microscopic in size and do not give a black cross under crossed nicols. × 60.

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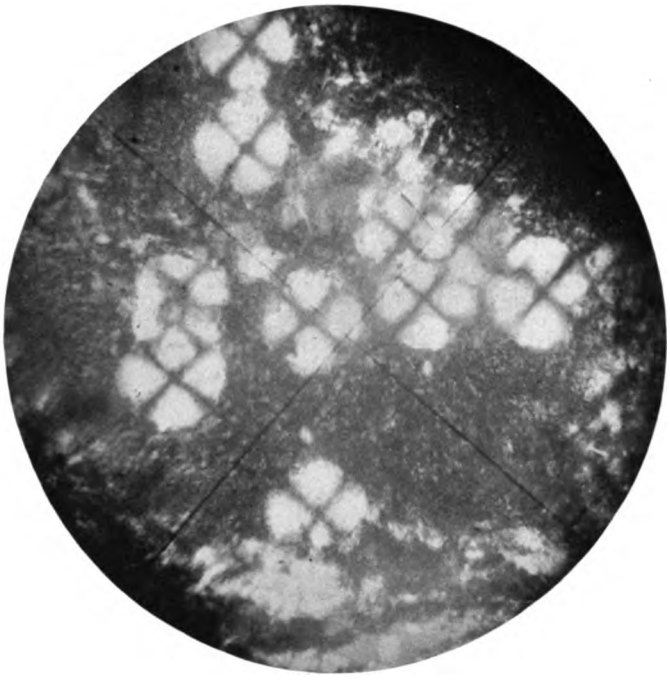

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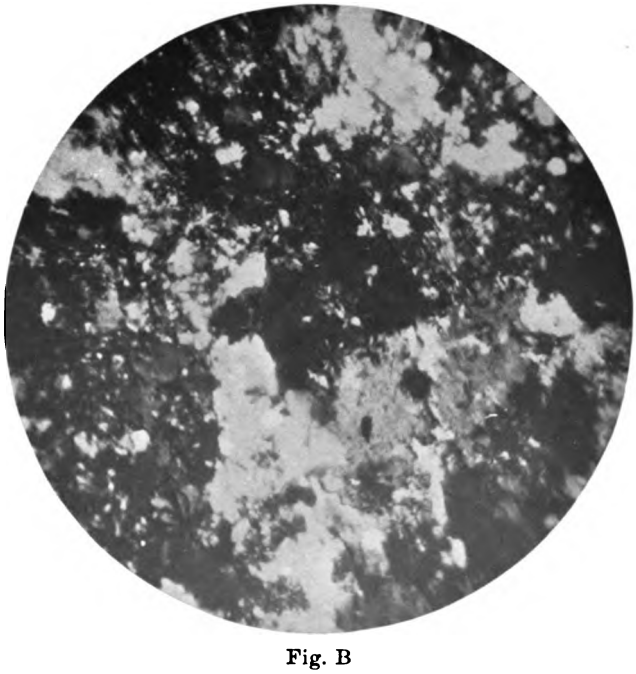

Fig. B

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EXPLANATION OF PLATE 26

Fig. A. A characteristic section of gouge surrounding the soft type of pyrite. It generally contains much pyrite and always shows evidence of movement in the breccia fragments included in it. Natural size.

Fig. B. Showing the metasomatic process at work in the formation of the hard type of pyrite. (*R*) Silicified rhyolite. (*S*) Sulphides. Natural size.

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Fig. A

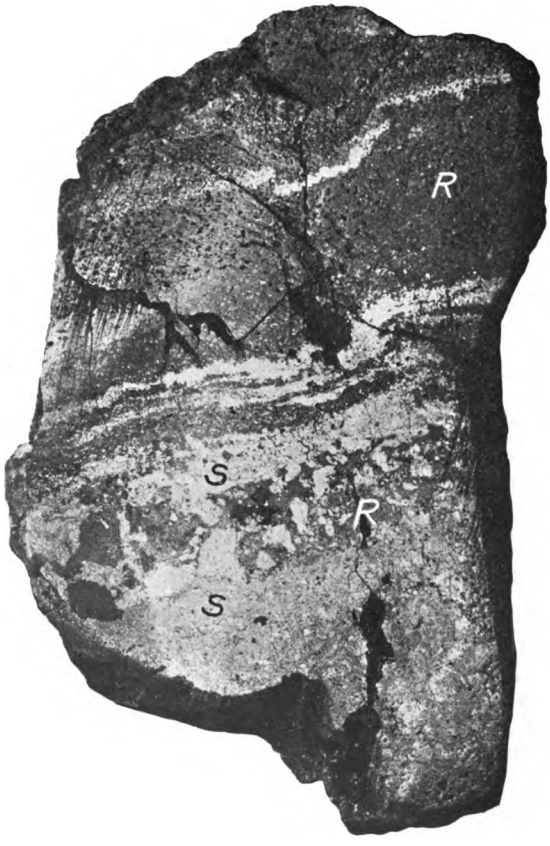

Fig. B

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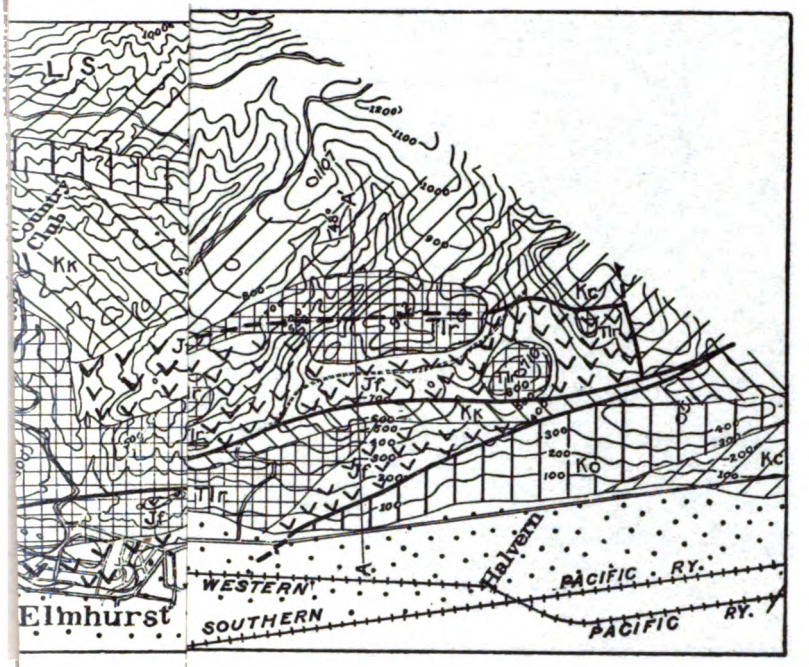

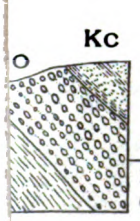

Pleistocene | Recent

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THE BRECCIAS OF THE MARIPOSA FORMATION IN THE VICINITY OF COLFAX, CALIFORNIA

BY
CLARENCE L. MOODY

UNIVERSITY OF CALIFORNIA PRESS
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INTRODUCTION

The Mariposa formation, which has long interested students of the Sierra Nevada, is exceptionally well exposed in the vicinity of Colfax; it is believed that a more favorable locality for the study of its stratigraphy will not be found.

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The present investigation was undertaken in the hope of securing definite evidence concerning the origin of the uncommon breccia beds which comprise about one-fifth of the formation in this vicinity. The main purpose of this paper, however, will have been accomplished if the attention of geologists is sufficiently called to the peculiarities of these beds to inspire a further investigation as to their origin. The chief stimulus that has lent zest to the investigation has been the suggestion by Professor A. C. Lawson that the breccia may be a Jurassic tillite. While the results obtained only partially support this view, its value as a working hypothesis is acknowledged with pleasure.

Free use of the folio of the United States Geological Survey covering this region has been made during the prosecution of the work.

LOCATION AND TOPOGRAPHY

The region studied lies in the southwest quarter of the Colfax quadrangle, California; it embraces an area of 60.5 square miles, with a length of 11 miles and a width of 5.5 miles. The accompanying map (pl. 28) shows the general features of the geography. Colfax, the only town of importance in the vicinity, is about sixty miles northeast of Sacramento.

The small area shown on the map is part of the foothill belt of the Sierra Nevada. The relief is pronounced and rapidly increases in ruggedness to the north and east, attaining a maximum at the crest of the range, about thirty miles northeast of Colfax. The highest eminence in the region under consideration is on Cape Horn Ridge northeast of Colfax; its elevation is 3100 feet. The lowest point is at the bottom of the cañon of the North Fork of the American River; the 900-foot contour crosses the stream just south of Owl Creek. The maximum relief is thus 2200 feet.

The dominant features of the topography are the cañons of the Bear River and of the North Fork of the American River. The Bear River takes its course diagonally across the northwestern corner of the area mapped. It occupies a large rugged cañon, with precipitous walls where the stream cuts through the plutonic mass northwest of Colfax, but with more gentle approaches in other tracts. Its chief tributary is the Greenhorn River with a small catchment basin west of Dutch Flat. The average grade of the Bear River within the limits of the map is 71 feet to the mile. The North Fork of the American River occupies a deeply incised trench with an average slope of the

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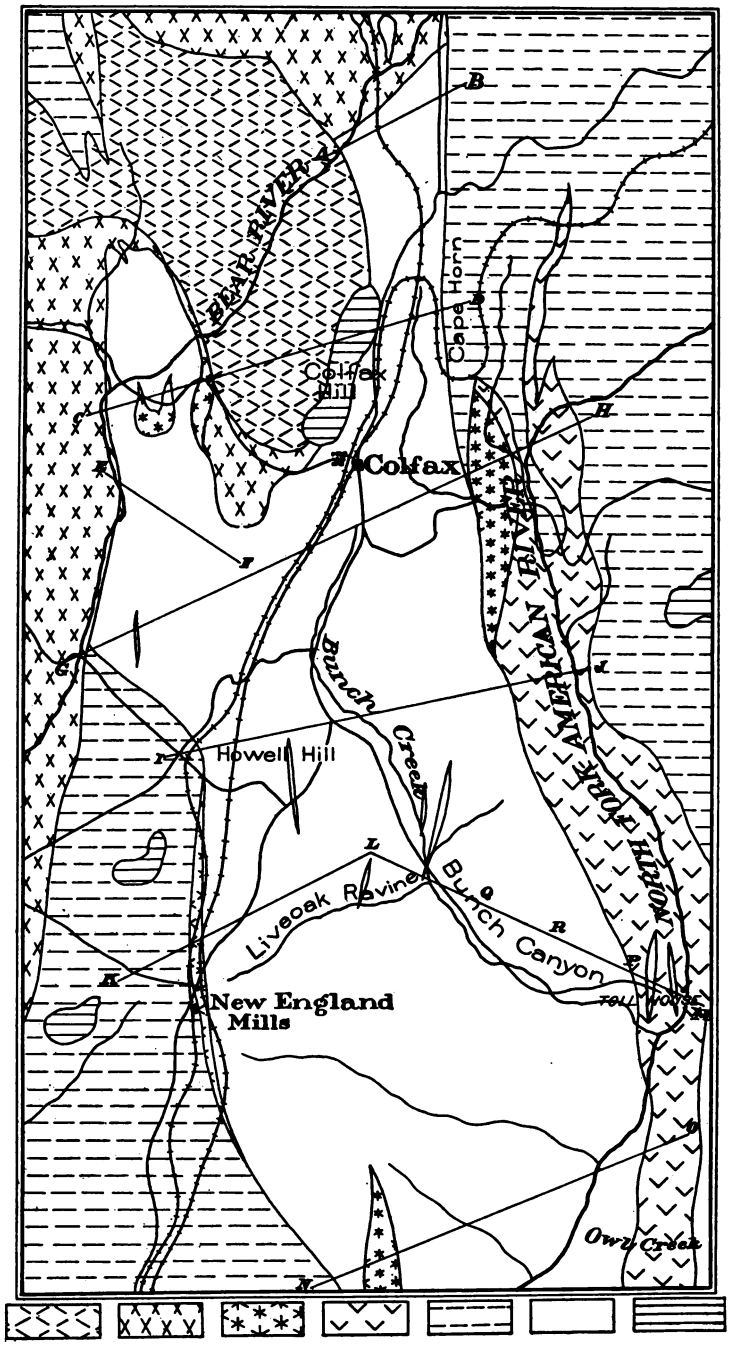

Geologic map of the Colfax Region

Scale: 1 mile

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walls of forty degrees. Little difference is to be found in the rate of erosion, measured in terms of steepness of slope, in the cañon; amphibolite seems no more resistant than the slates of the Mariposa. A great number of youthful, tumultuous streams are tributary to the North Fork. Robbers Ravine and the nameless gorge just east of Colfax drain the rugged region around Cape Horn. South of Colfax the drainage is chiefly into Bunch Cañon. Live Oak Creek, a tributary of Bunch Creek, and Bushy Creek, which flows directly into the North Fork, drains the high region around New England Mills. The eastern tributaries are Indian Creek, Bushy Creek and Owl Creek, all draining the Forest Hill divide just beyond the limits of the map. The average grade of the North Fork of the American River is 58 feet to the mile. The disparity in grade between the Bear and the American rivers has been shown by Lindgren to be due to the weakening of the activity of the former caused by the capture of its headwaters by the South Fork of the Yuba River in the vicinity of Emigrant Gap.

At least two cycles of erosion, separated by a period of extensive deposition are represented in the region, and each controls in a greater or less degree the development of present physiographic features. The first cycle appears in the old surface upon which the superjacent series was laid down. This surface has been extensively exhumed by the stripping away of the gravels and volcanic rocks which have accumulated since Cretaceous time. The surface is one of subdued relief carved in the massive, schistose and slaty rocks of the basement complex. The remnants of the superjacent series which are found on some of the hills determine a second surface of low relief, but of a totally different character; it is a graded, depositional surface. The present topography was evolved by the dissection of this graded surface by streams consequent upon a late uplift of the Sierra Nevada block. The present elevation of the range may have been attained in a double uplift, the first stage of which caused the removal of most of the superjacent series, and the second instituted the vigorous erosion that is still continuing in the carving out of the narrow, groove-like cañons in the basement rocks. The present streams flow in V-shaped trenches with abrupt approaches; lateral or tributary drainage has not been sufficiently advanced as yet to remove all of the once extensive superjacent series; outliers such as Howell Hill and Colfax Hill are abundant and characteristic of this, as of other parts of the foothill belt of the Sierra Nevada. In a word the present geomorphic cycle is still in a stage of early youth.

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GENERAL GEOLOGY

The geology of this small region is typical of the foothill belt of the entire Sierra Nevada; all the rocks, except granite, commonly found on the lower slopes of the range, occur within its limits.

The oldest rocks shown on the map belong to the Calaveras formation. In the folio of the United States Geological Survey covering this region five divisions of the Calaveras have been recognized, but for the purposes of this paper the general term Calaveras suffices. Four separate areas appear on the map. The formation west of New England Mills consists of a highly compressed series of black, clay slates and dark, argillaceous sandstones with several lenses and beds of limestone and bluish or grayish chert. The smaller area northwest of the Bear River is lithologically similar. Intermediate between these two localities on the east bank of the Bear River, directly west of Colfax, is a small outcrop of slate and slightly altered sandstone overlain by a thick mass of gray limestone which bears several species of lower Carboniferous fossils (see section EF, pl. 28). Forms referable to the anthozoan genera, *Clisiophyllum* and *Lithostrotion,* together with round crinoid stems were collected, while two species of *Pleurotomaria,* and one or two spirifiroid brachiopods were observed. In the northeastern part of the area the Calaveras rocks are fissile clay slates of a brownish to black color with a phyllitic development of mica, which gives them a lustrous, silvery aspect when weathered.

The Mariposa formation of Upper Jurassic age succeeds the Calaveras. It is generally regarded as the latest sedimentary formation of the Bedrock series. The area shown on the map represents the northern limit of a long belt of the formation traceable from Mariposa County. In this vicinity it consists of black slates alternating with dark gray sandstones and a great number of breccia beds. Its stratigraphy will be considered more at length later.

Igneous rocks are abundant in the area. The amphibolite belt which the American River cañon follows closely for some distance may represent flows contemporaneous with the deposition of the Mariposa sediments; long, narrow lenses of black slate included within the amphibolite, near the toll-house on the Forest Hill road, suggest this contemporaneity. Southward, however, and just east of the limit of the map, dikes of a material in every way similar to the amphibolite of the main belt clearly cut the Mariposa slate.

The diabase west of Bear River is regarded by Lindgren as representing lava flows possibly antedating the Mariposa depositional epoch.

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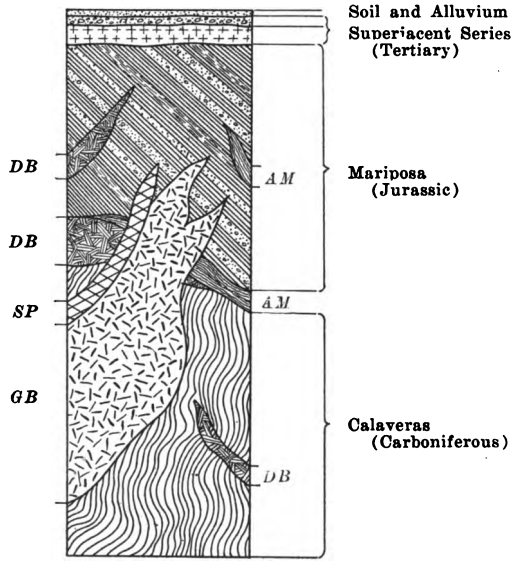
Part of the diabase is certainly irruptive, however; dikes of a porphyritic facies clearly intrude the Calaveras limestone shown in section EF, and other dikes may be seen crossing the Mariposa contact where exposed by the excavations for the Bear River canal. Numerous diabase dikes are included wholly within the Mariposa formation.

Serpentine, in dikes and masses, cuts the Mariposa and older formations. Its occurrence in dikes along contacts of both igneous and sedimentary rocks suggests that it represents a late phase of intrusion. The planes of schistosity of the Calaveras were, however, seen to pass obliquely across a serpentine dike near the Bear River,



AM, Amphibolite; *DB*, Diabase; *SP*, Serpentine; *GB*, Gabbro.

Fig. 1. Generalized columnar section

though other areas are wholly unsheared; the possibility of two periods of serpentine intrusion is thus indicated.

The elliptical area of gabbro, northwest of Colfax, is a coarse granitic rock of basic aspect, which has invaded the Mariposa, the older diabase and the Calaveras. The mapping suggests that this gabbro was brought into its present position by anticlinal folding, but its irruptive nature is indicated by chilled margins and discordance with the strike of the sedimentary beds.

The only other rocks in the vicinity of Colfax are the volcanic tuffs and river gravels of the superjacent series, which appear as outliers on the higher eminences of the region.

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STRATIGRAPHY OF THE MARIPOSA FORMATION

General Statement

The Mariposa formation is familiarly referred to as the "Mariposa slates," and this term is justified when the two long belts of dark sediments, stretching from Mariposa County to well north of the Mother Lode are considered. In many localities, however, coarser sediments are interbedded with the slates; thus in the Colfax region not over half the rocks of the formation are slate. Sandstones and grits are here well differentiated from the typical black, slaty argillites. Both within the slate and within the sandstone occur numerous beds of angular breccia and subordinate conglomerate lenses which persist on the strike and form bold ridges in the differential weathering of the series. It is estimated that one-fifth the volume of the Mariposa beds shown on the map is made up of this coarse material.

That the Mariposa formation as mapped is a stratigraphic unit cannot be denied. The relation of the breccia to the slate in the immediate vicinity of Colfax is somewhat obscured by the regolith as well as by minor faulting; but the sections exposed in Live Oak Ravine, in the American River cañon and on the Forest Hill road in Bunch Cañon, clearly show a conformable series of slates, sandstones and breccias interbedded and in places grading one into the other.

Columnar sections were made in the field showing the sequence of beds in Bunch Cañon and in Live Oak Ravine. A gradational series from breccia through grit and sandstone to slate is thus made evident. The thicknesses of the various members were estimated by pacing the horizontal distance. In some cases it was necessary to make arbitrary separations of the coarser sandstone from the breccia, and of the slate from the sandstone, where no such lines of separation actually exist. Some doubt must be entertained as to the number of beds indicated because of the possibility of repetition either by folding or faulting. The vertical section taken from Bunch Cañon, and shown in figure 2, is believed to be freer from these sources of difficulty as the dips are quite constant, except at *R*, and the beds are admirably exposed. Some indications of repetition by synclinal folding appear at *R*. If the section from *P* to *Q* is continuous, twenty-four beds of breccia, varying in thickness from two feet to four hundred feet, are interstratified with twenty-two slate bands, and fourteen beds of sandstone. From the anticline at *Q* to the intersection of Live Oak Ravine with Bunch Cañon six breccia beds, eleven sandstone beds and eight

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slaty bands were counted. In the Live Oak Ravine section four heavy breccia beds and seventeen sandstone members appear subordinate to twelve slate layers, some of which are over eight hundred feet thick. Frequent alternations of depositional conditions are thus indicated in Mariposa time, but the completeness of the gradations between the various lithologic types represented, and the large number of minor recurrences, make a subdivision of the formation impractical.

The lithologic distinctness of the Mariposa from the Calaveras formation is quite marked in the field. The chert, limestones and fissile slates and schists which characterize the latter are wholly lacking in the Mariposa. The boundaries are distinct in most places, and the alteration and deformation are decidedly greater in the older series. The conformable, gradational series of slates, sandstones and breccias mapped as the Mariposa, then, is comprised in a well differentiated formation.

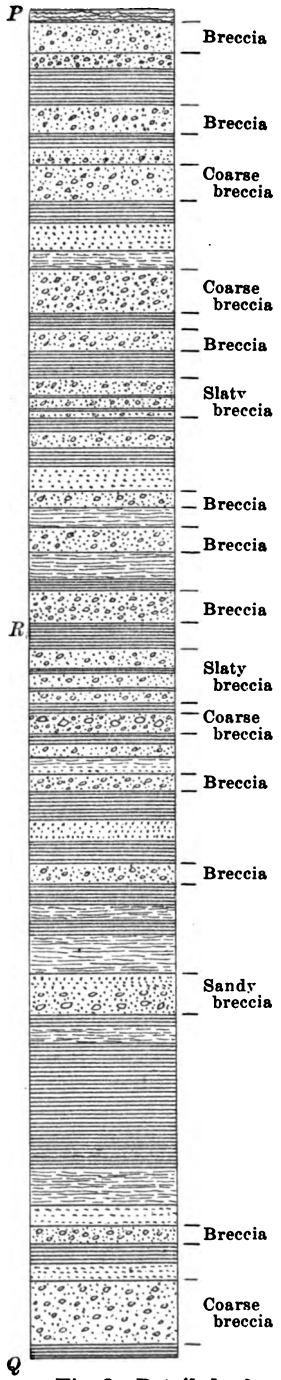

Fig. 2. Detailed columnar section between *P* and *Q*, structure section *KLM*. Thickness 5000 feet with possible repetition at *R*.

Slate

The slates of the Mariposa are more constant in petrographic character than are the sandstone and breccias. They are normally black, fine-grained shales or slates with a well pronounced slaty cleavage. A high degree of fissility is not attained by the slate; and arenaceous varieties, grading into sandstone, are quite abundant, particularly in the eastern part of the Mariposa belt. The exposures in the ravines and railroad cuts southwest of Colfax are generally of a rusty brown color, the result of weathering; below the regolith the slate is seen to be firm and black. Splendid outcrops of

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bluish-black slate occur in Bunch Cañon. The slaty cleavage is here wholly conformable with the planes of sedimentation, but this is by no means true in every outcrop. In many cases the lines of stratification run transverse to the direction of cleavage. Several instances of this are to be seen in Live Oak Ravine and in the second right-hand ravine tributary to Bunch Cañon. Figure 3 shows this feature in the upper course of Bunch Creek.

Microscopically the slate is seen to be composed of a very fine aggregate of altered mineral fragments, with an occasional small, angular quartz particle recognizable. The largest grain observed was

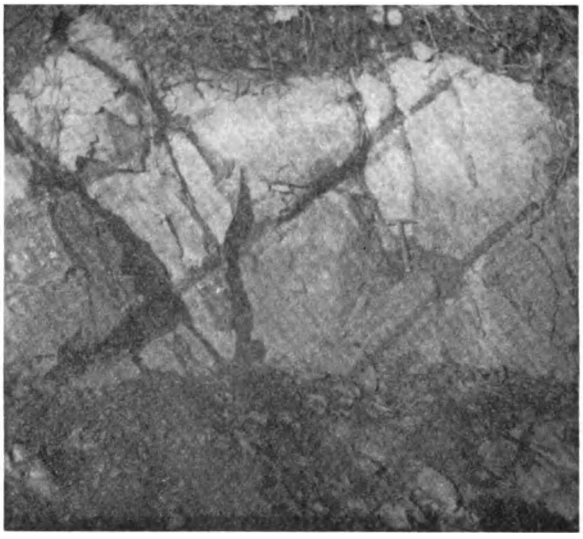

Fig. 3. Mariposa slate showing cleavage transverse to stratification. Bunch Creek.

less than 0.5 mm. in diameter. The rock is in no way remarkable; its petrographic features can be duplicated in most of our shale formations. Microscopic organisms were searched for in several slides but none were found.

Numerous quartz veins traverse the slate in the southern part of the area, but no important mines have been located on them.

SANDSTONE

With an increase in size of particles in the slate, sandstone is produced; gradation of particles from the finest up to the size of a pea are to be observed in hand specimens. These variable sandstones are

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more abundant in the eastern part of the area; particularly good exposures appear on the Nevada County narrow-gauge railroad near the Bear River bridge, and in the middle portion of Bunch Cañon. The main part of Bushy Cañon is cut in this rock. A tendency toward slaty cleavage is evident in all the sandstone examined, but this feature is far from the perfect development that it attains in the slates. In every observed case, this imperfect cleavage is parallel to the stratification planes.

Under the microscope the heterogeneity of the sandstone is quite marked. The individual particles grade in size from the finest up to the largest fragments in the breccia. As has been said, no definite line is to be drawn between sandstone on the one hand and breccia on the other. Angularity is the rule in the fragments large enough to be readily differentiated. Admixed with the angular material, however, are many subangular and even rounded grains of quartz, feldspar and limestone. The larger fragments are usually composed of limestone or chert; quartzite is commonly present, while fragments of amphibole-schist, diabase, basic lava, and slate appear subordinately. Plate 33, figure A, illustrates the main microscopic features of the rock.

The fresh sandstone is normally dark in color, but is locally of a greenish cast, due to the presence of chlorite stains.

BRECCIA

Occurrence

The most interesting and unusual lithologic type of the Mariposa formation is the coarser variety of clastic here termed "breccia."[1] Under this head are included the beds in which the larger constituent fragments range from the size of a pea up to a foot or more in maximum dimension.

The outcrops of the breccia are very striking, due to the great induration of the beds, which are by far the most resistant members of the formation. The ridge southwest of the nameless creek south of Bushy Cañon owes its prominence to a massive bed of this rock. The breccia here strikes across the bed of the American River and, because

[1] The word "breccia" has never been rigidly defined; it is here employed because of its lack of suggestion as to an hypothesis of origin. The term "conglomerate" is inapplicable because of the peculiar features of the deposit, as well as on account of the unavoidable connotation of ideas of origin which accompanies the use of this common, often too loosely applied, word. "Breccia," as here used, is a term co-ordinate with "glomerate," recently proposed by R. M. Field (Ottawa Nat., vol. 30, p. 31, 1916).

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of its superior hardness, has caused a marked constriction in the narrow cañon. Other thick breccia layers strike across Bunch Cañon and in each case the rock shows the same resistance to erosion. So thoroughly indurated is the breccia that artificial fractures as well as joints transect the included fragments. Weathered-out fragments are rare; the only places where they are notably developed are on the Colfax road, about a mile north of New England Mills, and near the point where the county road leading west from Colfax crosses the Bear River.

Breccia occurs at all horizons throughout the Mariposa, but is somewhat more abundant in the eastern part of the terrane; slate predominates in the western part. Thus only four well differentiated breccia beds appear in Live Oak Ravine, while twenty-four were counted on the Forest Hill road.

The several small cuts on the Nevada County narrow gauge line north of Colfax reveal a number of sandy beds which pass into coarser material in places. The second railroad cut south of the Bear River bridge is in a coarse, massive angular breccia in which spheroidal weathering is well-developed. Several coarse, angular fragments form the center of highly silicified sandstone bodies, several feet in diameter. These masses stand out prominently in the weathering of the cliffs, and might easily be mistaken for extra large boulders in the breccia. Their black color and extreme hardness tend to accentuate this possibility. Massive outcrops of rather uniformly angular breccia are to be seen just below the point where the county road crosses the narrow gauge line. Black slates lie above and below this mass. The prominent hill, southwest of Colfax, in the broad embayment of the triangular diabase area, is composed of coarse breccia with some slate beds. In the lower course of the Bear River a few thin beds of hard, angular breccia are interstratified with the typical black slates of the Mariposa.

The railroad cuts of the Central Pacific south of Colfax furnish excellent exposures of the various rock types of the Mariposa, but difficulty is experienced here in deciding as to the relation of the breccia to the slate; if it were not for sections showing this relation better elsewhere it might be assumed that the breccia was a separate formation. Faulting has contributed to the difficulties, but the chief of these is the wholly massive character of the breccia. In the second cut south of the town, great rounded masses of hard angular breccia project through a red mantle of decayed rock. Spheroidal weathering

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has produced striking exposures; the larger masses show several exfoliating layers, the smaller, one or two.

The heterogeneity of the breccia is perhaps better exemplified in this cut than in any other exposure visited. One small block contains fragments, from one to seven inches across, of chert, quartzite, limestone, gabbro, diabase, amphibole-schist, and one rounded pebble which is apparently a normal granite.

A splendid section of the entire Mariposa belt is obtained by following Live Oak Ravine from New England Mills to its juncture with Bunch Cañon, thence down the Forest Hill road to the amphibolite contact near the American River. The first breccia bed exposed in this section is well seen on the county road one mile north of New England Mills. Here a fifty foot bed of massive, unsorted material lies between fine black slates dipping 70° E. Throughout Live Oak Ravine coarse material is abundant in the sediments, but only four well-individualized breccia beds appear; the heaviest of these is perhaps seventy-five feet thick. Reference has already been made to the great number of breccia beds in the lower course of Bunch Cañon. All are unsorted, heterogeneous members of the series and are interbedded with slate and sandstone. (See detailed columnar section, fig. 2) In thickness the breccia beds range from two feet to four hundred feet. In one exposure the breccia is seen to be lenticular. Considerable mineralization has affected the Mariposa beds in the last two miles of section. Several prospect holes mark attempts to find wealth in the unresponsive rocks. One drift has been run over two hundred feet into the mountain side. It follows a small dislocation plane in the slate; the gouge has been recemented and sparsely charged with pyrite and less abundant chalcopyrite. Quartz and calcite veinlets cut through slate, sandstone and breccia indifferently, and the above mentioned sulphides are found disseminated in the coarser clastics. The last member of the series, west of the amphibolite belt, is a massive breccia bed which has been so thoroughly silicified and recemented that it presents quite a different appearance from the usual breccia of the formation; it is hard, dense and almost uniformly aphanitic, except in favorable spots where differential weathering has left a few fragments in relief. The rock is pyritized. The Annie Laurie mine, one of the more pretentious prospects of the region, is situated on the amphibolite contact in this pyritized zone.

An instructive outcrop occurs in Bunch Cañon about one mile north of its junction with Live Oak Ravine. At the point where the creek

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crosses the stage road a great bed of breccia has been incised and polished by the abrasion of the little stream, so that an extensive surface is presented for study. Figure A in plate 31 rather inadequately shows the locality; a number of tortuous bands of black slate occur within a massive bed of coarse breccia. The slate areas which are greatly elongated in the direction of the general strike of the breccia bed represent muds which accumulated and solidified contemporaneously with the coarse material; some of the slate bands are seen to feather out into the coarser sandstone matrix.

The American River Cañon is replete with bold outcrops of the breccia. Beds interstratified with slate occur well up to the serpentine contact on the west. The exposure is in the bed of the river. Reference has already been made to the thick bed of breccia at the small suspension bridge which spans the American River at a point about one-half mile southwest of Owl Creek. Some of the included boulders are rounded; they range in size up to fourteen inches in diameter.

MEGASCOPIC FEATURES

Texturally the breccia grades from fine to extremely coarse; this gradation is both lateral and vertical and, although usually gradual, may be abrupt along the dip. Viewed broadly the breccia is essentially a variable aggregate of angular, subangular and rounded boulders, for the most part unevenly distributed through a matrix varying from coarse sand to fine mud. Sorting action is rare. The variation of the coarse material is in four directions, namely abundance, size, composition, and degree of rounding.

Nearly every bed has a different ratio between coarse and fine material; in some cases the fine material is subordinate, in others only a few scattered blocks occur in an otherwise medium-grained argillaceous sandstone. In no case, however, is there a total lack of fine grained material.

The average size of the included fragments is approximately one inch. By this is meant that most of the pebbles are of this dimension; however, the variation both above and below this figure is so great that a wholly inadequate conception of the appearance of the rock is conveyed by any statement as to the average size of the component fragments. In general the size of the fragments ranges from a fraction of an inch up to three feet in maximum dimension. The ratio of abundance of fragments between two inches and one-half inch to

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those having a maximum dimension of three feet is estimated to be about 100:1. Particles less than one-half inch in diameter are of course far more numerous than all the others; it appeared in the field that the material of this size constitutes from three-eighths to one-half the volume of the entire rock. Many holes or cavernous spaces, with somewhat more restricted limits of size than the included fragments, indicate former limestone fragments which have been dissolved in the meteoric circulation.

The vicissitudes through which the Mariposa rocks have passed are not reflected to any great extent in the breccia. The pebbles have suffered very little, if any, deformation; it is only in the finer facies that any perceptible shearing planes have been developed. The coarser rocks are typically massive; they fracture indifferently in any direction.

The argillaceous matrix of the breccia is, in the hand-specimen, well differentiated from the coarser particles of the rock. It is in every way like the black slates with which the breccias are intercalated, and, where sufficiently abundant, shows slaty cleavage in the direction of prevailing schistosity.

The pebbles and boulders included in the breccia represent a wide range of rock types. Perhaps the most abundant rock represented is chert. Black, gray and green fragments, always wholly angular, occur in nearly every other outcrop; they are in no way different from the fragments that now mantle the hillsides in the Calaveras area to the west. Next in abundance are limestone pebbles usually of a dark gray color and either angular or subangular in outline. Rounded as well as angular and subangular pebbles of diabase are quite abundant. Of equal prominence are quartz pebbles, which on the whole are moderately well water-worn; few of them can be called angular. Boulders up to a foot in diameter are not uncommon. Subordinately appear blocks of gabbro, basic lava, amphibole-schist, mica-schist, slate, friable sandstone and felsite. One pebble showing quartz and feldspar twinned on the Carlsbad law was seen in the exposure of massive breccia west of Colfax. It seemed to be a typical granite. Fairbanks[2] also reports granite boulders from the Mariposa in the vicinity.

Rounded, water-worn material is not wanting in the breccia; in fact some of the exposures east of Colfax contain it in some abundance, so that the breccia in places passes into normal conglomerate. In the main, however, angular and subangular material predominates, and it

[2] Fairbanks, H. W., Jour. Geol., vol. 5, no. 1, p. 76, 1897.

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is this type of fragment that lends distinction to the breccia. In general the pebbles are pockety and unsorted and the longer axes of the flat fragments often transgress the bedding planes.

Certain phenomena appear in a study of the disposition of some of the coarse blocks which are very difficult to explain without recourse to the transporting action of ice. I refer to the rather exceptional occurrence of single or nearly isolated boulders, some of them ranging in size up to a yard in maximum dimension, entirely within rather thin-bedded slate. Plate 33, figure B, shows a chert boulder three feet in diameter, in a railroad cut just south of Colfax, which is embedded within an arenaceous slate. The boulder is now rather extensively broken down by weathering, but it was evidently somewhat rounded

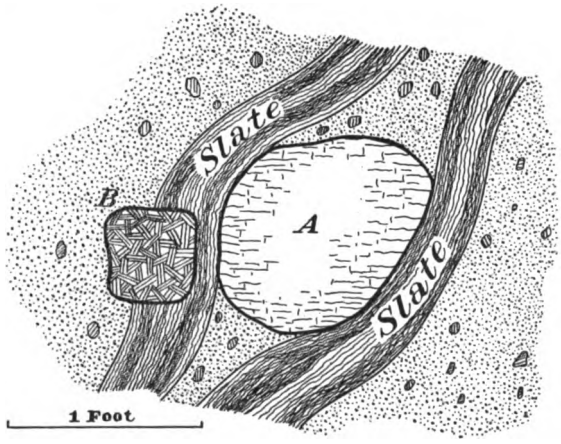

Fig. 4. Boulders in finer sediments of Mariposa breccia. North Fork of American River between Owl and Bushy creeks.

by water wear before its deposition in its fine-grained matrix. Other blocks of a similar nature occur in this outcrop of the breccia.

The photographs shown in plate 32 were obtained in the bed of the North Fork of the American River between Owl and Bushy creeks. They illustrate the isolated boulders which are rather abundant in the finer sediments prevailing in this cañon. Eight or ten inches is the average diameter of the coarser material here observed. The boulders all show some evidence of water wear; some of them may even be said to be well rounded. In both the photographs fine-bedded slate is observed to pass around the central boulder; in figure B this may be due to shearing, although it has the appearance of original sedimentation, but in figure A appears a feature which is rather suggestive

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of the impact phenomena sometimes observed where floating ice is an important agent of transportation. The accompanying sketch (fig. 4) shows diagrammatically the relations in this exposure. A quartzite boulder (*A*) ten inches in diameter, elongated in the direction of the bedding of the finer sediments, lies in a depression in a thin slate lens, and is overlain by a second slate stratum which arches over it in a pronounced curve; in the upper stratum a diabase block (*B*) is distinctly embedded in the fine, slaty material, the sedimentary planes coming squarely up to the subangular block and not passing around it. The attitude of block *B* is such that it could not possibly have been laid down contemporaneously with the argillaceous material of the slate; it must have been dropped into its present position after the upper slate stratum was laid down. This occurrence is, however, not typically that observed where evidences of impact are clearly preserved; no crater development is to be seen in the slaty material surrounding the boulder.

Microscopic Features

A microscopic examination of the breccia was undertaken in the hope of gaining some clue as to its origin, as reflected in the nature of the matrix. The accompanying photomicrographs (pl. 30) show the features revealed in thin section.

Microscopically the matrix is seen to grade from coarse sand down to a fine, felty aggregate which is unresolvable under the microscope. Petrographically it is quite similar to the black slate of the series, the only difference being that it contains larger recognizable particles. These larger particles usually consist of quartz, but some very fine chert granules are to be seen. The recognizable fragments, like their large relatives, are chiefly angular or subangular (fig. A), although somewhat rounded ones also occur (fig. B). The degree of comminution, then, is the only apparent difference between the fine and coarse phases of the rock.

BRECCIAS IN OTHER AREAS OF THE MARIPOSA

The area of the Mariposa beds shown on the map represents the northernmost extension of a remarkably persistent narrow belt of similar beds which traverses the entire Mother Lode district. Breccias are present throughout this extent, and although they vary consider-

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ably in abundance are apparently nowhere so well developed as in the region described.

The series of breccias of the Colfax area continues into the Placerville quadrangle to the south. Lindgren and Turner[3] refer to them here as "a series of dark, partly volcanic sandstones and breccias intercalated among the slates."

Farther south the breccia becomes less abundant. Near Plymouth, in the Jackson quadrangle, occur two or three beds interstratified with the clay slates and schistose sandstones. Southwest of San Andreas the conglomerate is described[4] as largely replacing the slate. Near Angel's Camp breccia and tuff are interbedded with slate. Ransome[5] regards the Mariposa section of Woods Creek in the Sonora quadrangle south of Table Mountain as affording the best exposures in the Mother Lode belt. Here are interbedded slates, schistose sandstone and conglomerates. The latter are not always persistent, but often pass irregularly into sandstone and slate. These observations tend to show that the breccia phenomena are not to be referred to some local, peculiar condition; the agencies which produced them were general and widespread.

On Dry Creek, west of Drytown, Amador County, occurs a ten-foot bed of brecciated material consisting of fragments of quartz, quartzite, chert, limestone and various igneous rocks, ranging from angular to well-rounded in outline and cemented by a phyllitic matrix. This bed was mapped by Ransome as a part of the Calaveras formation, but as mentioned in the text of the Mother Lode folio, its relations to the Mariposa were not plain. It may belong to the series which runs north to Colfax. Dr. Adolph Knopf, who has first hand knowledge of the occurrence, is of the opinion[6] that this bed represents either a fanglomerate or a tillite with the probabilities favoring the latter hypothesis.

PALAEONTOLOGIC EVIDENCE

The fauna of the Mariposa formation throughout its whole extent is sufficient to place the age of the beds as Upper Jurassic. Dr. Stanton and Professor J. P. Smith concur in this determination. Within the limits of the area studied, however, only two forms have been discovered which are of palaeontologic significance. These are

[3] Lindgren, W. and Turner, H. W., U. S. Geol. Surv. Folio, no. 3.
[4] Ransome, F. L., U. S. Geol. Surv. Folio, no. 63.
[5] *Loc. cit.*
[6] Personal communication.

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Perisphinctes colfaxi Gabb, found in the railroad cut one mile south of Colfax, and *Olcostephanus lindgreni* Hyatt, which occurs in rusty, brown, sandy slate about one-half mile west of the first locality. These ammonites point to an Upper Jurassic age.

Since these fossils have been obtained from beds with which the breccias are interstratified, it was thought well to obtain what evidence they furnish as to the climatic conditions under which the deposits formed. In answer to a request for such information, Professor J. P. Smith replied:[7] "The fossils of the Mariposa do not give much indication as to climate except that they are all of northern kinship. That may not mean cold, though it possibly means a cooler climate than the Middle Jurassic."

The occurrence of ammonites in the slate, however, indicates that this portion of the series at least is marine, and any hypothesis explaining the origin of the beds must take cognizance of this fact.

CLASSIFICATION OF RELATED CONGLOMERATES

General Statement

In arriving at a correct understanding of the origin of the Mariposa breccias it will be necessary to review in a few words the various conglomerate types now recognized and to institute comparisons between them and the rock under discussion.

Such a study was made ten years ago by G. R. Mansfield[8] in an investigation of the stratigraphy of the Boston Basin, and his results have proved of great value in the preparation of this paper. He divided conglomerates into six types, classified on the basis of their origin, as follows: (1) marine, (2) fluviatile, (3) estuarine, (4) lacustrine, (5) glacial, (6) crush-conglomerate. Of these (4) and (6) require no further consideration since the Mariposa breccias are interstratified with marine beds, and since the heterogeneity of the pebbles precludes the possibility of their formation by the brecciation of any single rock. There then remain for consideration marine, fluviatile, estuarine, and glacial conglomerates. To these must be added an important class of clastic deposits recently described by Professor A. C. Lawson[9] as fanglomerate. The origin of the Colfax rocks is

[7] Personal communication.

[8] Mansfield, G. R., The origin and structure of the Roxbury conglomerate, Bull. Mus. Comp. Zool. Harvard College, no. 49, Geol. ser., vol. 8, no. 4, 1906.

[9] The petrographic designation of alluvial fan formations, Univ. Calif. Publ. Bull. Dept. Geology., vol. 7, no. 15, 1913.

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certainly comprised in the processes which have given rise to the above mentioned types, but the fact must not be lost sight of that two or more processes may have operated to produce the breccias.

MARINE[10]

Typical marine conglomerates have clean, well-marked and sorted sand as a matrix. When in quantity the sand may be more or less cross-bedded; the grains vary from angular to rounded. The component pebbles of the rock are usually of material of local origin; they are uniform in size and are ordinarily well rounded. The stratification of marine conglomerates is usually well marked and cross-bedding may be more or less perfectly developed. In the normal cycle of sedimentation, following an encroaching sea, finer material will overlie the coarse and may locally interdigitate with it. Local unconformities and irregularities may be expected along the dip but great persistence and uniformity is common along the strike. In general, true marine conglomerates are not thick; Barrell[11] states that their thickness is usually less than one hundred feet.

Mansfield has cited the Cretaceous of Texas as a typical example of a series of marine deposits. The Trinity sands, described by Hill,[12] as the basal formation, have as their lowest member a fine pebble conglomerate, consisting of small masses of the adjacent pre-existing rocks in a cement of ferruginous yellow and red gritty sand. Most of the coarser material is well rounded and sorted, though in some localities it is predominantly subangular with only the more resistant quartz, which has travelled a long distance, well rounded. The basal conglomerate grades upwards into sands, grits, and silts; it is seldom over two hundred feet thick. Both massive and well-bedded deposits occur in the formation; sands and clays are interstratified with the conglomerate in places, while elsewhere the beds are dominantly coarse.

Other typical marine conglomerates, deposited in an encroaching sea, are abundant in the stratigraphy of the western part of the United States. Among them might be mentioned the Scanlon and Barnes arkosic conglomerates described by Ransome[13] from the Globe district.

The following points of difference may be pointed out between the Mariposa breccias and typical marine deposits of that type: (1)

[10] Mansfield, *loc. cit.*, pp. 107–150.

[11] Barrell, J., Abstract: Bull. Geol. Soc. Amer., vol. 20, p. 620, 1909.

[12] Hill, R. T., Twenty-first Annual Report, U. S. Geol. Surv., pt. 7, 1901.

[13] Ransome, F. L., U. S. Geol. Surv. Prof. Paper, no. 12, pp. 30–31, 1903.

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angular material predominates in every exposure of the Mariposa; in some, no rounded material is visible; (2) the pebbles are unsorted, distinct bedding is often lacking; (3) the matrix is largely silty.

Fluviatile

Conglomerates referable to stream action usually have a matrix of sand mixed with fine and coarse material which is, in general, not well sorted and may be cross-bedded; the individual grains vary from angular to partly rounded. The coarser material ordinarily consists of locally derived masses which may range up to several tons in weight; the boulders vary from well-rounded to subangular. Frequent alternations of coarse and fine beds, both commonly showing current markings, oblique lamination and numerous irregularities in thickness and composition characterize such deposits. The thickness of flood-plain conglomerates may be very great.

Instances of conglomerates of this type are to be found all over the world. The Siwalik Group, a Tertiary deposit of India, with a maximum thickness of 14,000 feet is regarded by Geikie[14] as of fluviatile origin. Fluviatile deposits occur in the upper Old Red Sandstone of Great Britain,[15] in the High Plateaus of Utah, described by Dutton,[16] where angular material predominates and in the Great Valley of California as discussed by Ransome.[17] The auriferous gravels of the Sierra Nevada form one of the most typical of fluviatile deposits yet described.

The predominance of rounded and subangular pebbles in typical fluviatile conglomerate is not realized in the Mariposa beds. As will appear in the sequel, however, it is believed that streams of high grade may have been instrumental in transporting the material which now makes up the formation.

The deposits termed "estuarine"[18] by Mansfield are not essentially distinct from those of fluviatile origin; as he uses the term it is apparently intended to be restricted to the deposits accumulated in the delta portion of streams. This class of deposits is summarized by Bailey Willis[19] in the following statement:

> The unassorted mingling of sandy and clayey particles is the result of rapid deposition at the mouths of muddy streams in opposition to waves that are too weak to sort and distribute the volume of sediment. This is a condition

[14] Geikie, A., Textbook of Geology, ed. 3, p. 1021.
[15] *Op. cit.*, ed. 3, p. 802.
[16] Report on the geology of the high plateaus of Utah, 1880.
[17] Ransome, F. L., Univ. Calif. Publ. Bull. Dept. Geol., vol. 1, no. 14.
[18] *Loc. cit.*, pp. 121–122.
[19] Willis, Bailey, Maryland Geol. Surv., vol. 4, p. 63, 1902.

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of delta building. The frequent and irregular interbedding of coarse sands, sandy clays and clays, the cross-stratified beds, the ripple-marked and sun-cracked mud surfaces, the channels scoured by transitory streams, all prove the abundance of sediments, the shifting conditions of deposition, the irregularity of currents, the wide expanse of tide-flats and shallow waters and the weakness of the waves.

The admixture of fine and coarse material and the frequent alternations in the series at Colfax conform very well to this general type of delta deposits. Cross-bedding was, however, not observed in these rocks, and other evidences of current action even in the less coarse sediments are not at all apparent.

GLACIAL

The consolidated debris transported by glacial agencies has been termed "tillite" by Professor Penck. Glacial deposits are characteristically heterogeneous aggregates of finer and coarser material, compacted but wholly unsorted. The matrix of the coarser phases usually consists of angular grains of minerals and rocks, fresh feldspar and quartz in very finely divided particles being especially abundant. The individual grains of the matrix are commonly partly rounded and partly angular. The coarser pebbles and boulders are generally locally derived, but considerable proportions may come from distant sources. Within a tillite, little if any assortment is to be expected; masses up to several tons in weight may repose in an argillaceous matrix. The shape of the pebbles in a glacial deposit is of great diagnostic significance. Such ice-borne fragments are faceted occasionally and sometimes have their edges rounded and ends snubbed. The surface of at least a few of the pebbles is sure to be polished and striated, with the majority of the striae paralleling the long axis of the stone. Tillites are usually not bedded, although some may show an obscure stratification; sometimes pockets, lenses, and beds of coarser and finer false-bedded material may be included in the unstratified mass.

Such deposits as above described are due to the deposition of material as moraines, eskers and kames, but other types of glacial deposits are known. Thus in glacial-fed streams a well differentiated type of deposit results which may here be termed fluvo-glacial; all gradations from typical tillite to well-marked fluviatile deposits may be anticipated in such a deposit. In the case of a glacier directly facing the sea, the reworked till may be sorted and well-bedded and

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usually exhibits sharply individualized beds of coarse and fine material alternating in a variable sequence.

The importance of glaciers as agents of transportation and deposition both in early as well as late geologic time is now generally accepted. Shaler and Davis,[20] as early as 1881, recognized, beside Quarternary glaciation, evidence of glacial action in the Superga Miocene of Italy, in the Eocene of Switzerland, in the Chalk of England, in the Jurassic of Scotland, in the Triassic of eastern United States, and in the Permian, Subcarboniferous (Mississippian), Devonian, upper Silurian and Cambrian in various areas throughout the earth. Their views have been somewhat modified by later work, but deposits referable to glacial agencies have since been found of even greater age than they then surmised. No general exception then can be taken to the possibility of glaciation in the Mariposa.

The Permo-Carboniferous Talchir group of India described by White,[21] Oldham and others is a typical glacial deposit. It consists of 500–800 feet of clays, fine silts, boulders, sandy shales, conglomerates, and soft sandstones. The included fragments are everywhere subangular, and are mostly derived from distant localities. Large boulders often lie embedded in silt too fine to admit any explanation except that of deposition from floating ice. Smoothed and striated stones are frequent in the unsorted masses.

Boulder beds very similar to those of India occur in New South Wales, Australia, and in South Africa. The Dwyka Conglomerate in the latter area is now well known in the literature of glaciology. A good description of this formation is given by Mellor.[22] The rock is usually bluish or green and consists of fragments of a number of mineral species. Within the mud matrix are included a vast number of boulders and pebbles of a variety of rocks, scattered irregularly and indiscriminately throughout its mass. Many of the boulders are rounded; many others are flattened and striated in two or more directions. Lenticular patches of shales and mudstones, apparently deposited in pockets in the conglomerate, consist of the finest glacial mud. Professor Davis[23] remarks that since no marine deposits are associated with the formation, which extends over thousands of miles, he considers that the Dwyka ice was a continental sheet analogous to the Pleistocene glaciers of the northern hemisphere. Beautifully

[20] Shaler and Davis, W. M., Glaciers, p. 102, 1881.
[21] White, C. D., American Geologist, vol. 3, p. 299, 1889.
[22] Mellor, E. T., Quar. Jour. Geol. Soc., vol. 61, pp. 683–86, 1905.
[23] Davis, W. M., Bull. Geol. Soc. Amer., vol. 17, p. 413.

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glaciated rock floors are found underlying the formation in various localities. Oldham and others have correlated the Dwyka with the Australian tillite and with the Talchir group of India.

In North America the recognition of the glacial origin of the basal conglomerate of the Cobalt series marks an important advance in our knowledge of geological history. To A. P. Coleman[24] is due the credit of this important discovery. Wherever exposed the lower part of the Cobalt series is seen to be a wonderfully thick, heterogeneous conglomerate. Hore[25] gives a good description of the rock. It consists of a great variety of types and sizes of boulders with very little sorting in evidence. Large, isolated boulders sometimes occur in clay slates; the larger masses are usually rounded or subangular, some are markedly angular. The matrix is ordinarily graywacke with an occasional slate pocket; numerous particles of quartz, feldspar, chert and felsite are to be seen under the microscope. Some fine-grained turbid matter in the matrix contains chlorite, thus differing from the Dwyka. Within the deposit, sudden lateral and vertical changes often occur; shales are frequently interbedded with coarse material; quartzites, rapidly grading into akrose, interdigitate with the coarser facies. Coleman[26] describes and figures well-preserved striations on some of the boulders; they show best on felsites and fine-grained greenstones; many of the surfaces are well polished. In the Cobalt tillite it has been possible to differentiate various types of glacial debris; thus widely separated fragments in a medium-grained matrix indicate ground moraine; wholly coarse material is considered as representing the terminal moraine, while various aggregates of rudely sorted, rounded pebbles mark the sites of ancient kames. In arriving at a conclusion as to the origin of the Cobalt conglomerate, Coleman considered and rejected hypotheses involving crushing, faulting, talus formation, and exceptionally heavy river currents. The tillite is interbedded with slate layers up to five hundred feet in thickness, which are considered to represent deposition during interglacial periods. The formation stretches over thousands of square miles and thus probably indicates the extension of a great ice-sheet over the continent in that remote time.

Other ancient tillites in America have been found by Sayles[27] in

[24] Coleman, A. P., Jour. Geol., vol. 16, pp. 149–158, 1908.

[25] Hore, R. E., Jour. Geol., vol. 18, no. 5, pp. 459–67, 1910.

[26] *Loc. cit.*

[27] Sayles, R. W., Harv. Mus. Comp. Zool., vol. 56, no. 2, 1914.

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the Boston Basin, and by Atwood[28] in the Eocene of southwestern Colorado. The probability of a glacial origin for the Mariposa breccia will be considered later.

Fanglomerates

This term was proposed by Professor Lawson[29] as a petrographic designation for the coarser portions of alluvial fan formations. Aridity and high relief are postulated in ascribing a fan origin to a deposit. The constituents of a fanglomerate range from the coarsest material down to fine sand. Blocks of extraordinary size are apt to appear at the apex of a fan, and occasional ones, a foot or more in diameter, are found far down the slope where the average size of the material is less than one inch in maximum dimension. A gradation in size of material from coarse to fine is, however, to be anticipated as one progresses from the apex to the lower slopes of such a formation; the normal sequence is fanglomerate, arkose, silt, the latter representing playa, lake or river flood-plain detritus. In any given point within an alluvial fan formation sorting action is very imperfect; the sorting is chiefly that represented by the gradational change from coarse to fine material in a lateral direction. The cement of a fanglomerate cannot be fine grained; silt only appears near the playa end of a fan. In general the matrix of such a deposit will be medium to coarse sand. Of course infiltration may later cement the rock to such an extent that it will fracture indifferently through, rather than around, the included fragments. The masses included in a fanglomerate can never have traveled a great distance; they are usually of the same composition as the steep mountain slopes at the base of which they lie. Occasional water-worn boulders are to be found admixed with angular to subangular material which makes up the greater portion of the rock.

The argillaceous matrix of the Mariposa breccia is considered a serious objection to an hypothesis of origin involving typical alluvial fans of the desert type. Further, since marine beds are certainly interstratified with the breccias, even though they themselves were not laid down in the sea, the conditions for the formation of typical fanglomerates were certainly not realized. The probability of desert-fans having played a part in the origin of the beds under consideration is, then, held to be rather remote. The conception of alluvial deposits

[28] Atwood, W. A., U. S. Geol. Surv. Prof. Paper, no 95-B, 1915.

[29] *Op. cit.*

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developed under the humid cycle is, however, believed to furnish a possible solution of the problem of origin.

PROBABLE ORIGIN OF THE BRECCIA

We have here to deal with a normal conformable series of strata progressing in the main from coarse to fine, although occasionally exhibiting a sudden discontinuous change from fine to coarse. The slaty facies of the series is of marine origin; the breccia, which is interbedded with it, must clearly have been deposited in a marine basin. The problem is then to explain the occurrence of angular pebbles in a fine arenaceous to a silty matrix.

It is obvious that wave action must have been at a minimum during the period of accumulation of the coarse material. It is equally certain that transportation by fluviatile agencies took place if at all only through short distances. The material of the larger fragments is all derived from the Calaveras rocks exposed in the immediate vicinity, comprising chert, limestone, slate, sandstone, and schists of various types, as well as the more common basic igneous rocks, which make up this older series. Quartz pebbles alone seem to have been transported some distance; quartz veins do occur in the Calaveras, but they may belong to the same period of mineralization which affected the Mariposa at the time of the production of the great Mother Lode belt to the south, but as these pebbles are in general rounded they may be considered to have come from a distance.

In discussing the evidence for the Mariposa-Calaveras unconformity Turner[30] states that the two distinct belts of the Mariposa in and south of the Jackson quadrangle were deposited in long, narrow troughs between Calaveras ridges, and that later the beds were infolded with the Carboniferous series. Intrusive and extrusive igneous action as well as adjustment of stresses through folding and perhaps faulting prepared a Jurassic surface of marked relief in which two long, narrow basins roughly parallel and striking in a northwest-southeast direction, connected with the open sea probably to the southeast. These troughs received the sediments which we now know as the Mariposa beds.

The opinion of Lindgren[31] as to the origin of the Mariposa of the Colfax region is expressed as follows: "The formation was clearly

[30] Turner, H. W., Fourteenth Annual Report, U. S. Geol. Surv., pp. 456–457, 1892.

[31] Lindgren, W., U. S. Geol. Surv. Folio, no. 66, p. 3.

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deposited in a gulf or shallow bay, the conglomerates indicating the immediate proximity of the shore line."

Two alternative hypotheses of origin merit consideration; the first, is that the breccias are consolidated glacial debris, the second, that they represent alluvial material derived under the humid cycle. The latter theory is essentially only an extension of the views of Lindgren and Turner.

The Mariposa breccias unquestionably resemble many typical tillites. The admixture of rounded, subrounded and angular boulders in an unsorted matrix of less coarse material, which is often silty, is a feature which characterizes all tillites from the most ancient to the most recent. Interbedding of such glacial deposits with slates is rather a common feature; several slate beds are intercalated in the Cobalt tillite, they characterize the Dwyka of Africa, and in the Permo-Carboniferous tillite of Australia, six slate horizons, bearing a marine fauna, alternate with the coarser glacial beds. In addition to these characteristics common to all well authenticated tillites, positive evidences of glacial action, particularly the striating and faceting of pebbles, are observed in the actual deposits, while in most cases a polished, fluted and striated surface is found underlying the morainal material. Such lines of evidence are of course actual demonstrations of extensive glaciation, but their apparent absence cannot be held to disprove any hypothesis of glacial origin. Careful search in all the outcrops of the Mariposa in the vicinity of Colfax have so far failed to reveal any typically glaciated pebbles. Some striations were observed, but all these appeared to be due to cracks or weaknesses in the rock; flattened and snubbed pebbles were nowhere found. Further, the surface upon which the Mariposa beds were laid down is very poorly exposed in the region; the western Calaveras contact is the only one which might offer an opportunity for observation; the other contacts are against irrupted masses. Unfortunately this only known normal contact is covered throughout with rock-waste. It is thus unknown whether or not the formation rests on a glaciated surface. However, since marine beds are interstratified with the coarse deposits, if their origin is to be referred to glacial action, the glaciated floor from which the debris was swept would probably be outside the marine basin in which the deposits accumulated, and, as acute deformation and extensive denudation have affected the region, resulting in the removal of a larger part of the rocks which bordered the basin, the discovery of a glaciated surface is hardly to be expected. Dr. Knopf

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has suggested that striations might become obliterated during the vicissitudes through which the beds have passed; the Dwyka, Talchir and Australian Permian tillites in which striated pebbles are so abundant, have suffered very little of the intense deformation which has visited the Mariposa. The remarkable preservation of striations on pebbles from the Cobalt tillite, however, shows that once the seal of glaciation is imprinted it becomes well-nigh ineradicable. It should at this point be noted that many Pleistocene moraines yield few or no striated pebbles, so that their original absence does not seriously affect the evidence favoring a glacial origin for the beds.

In the great glacial horizons of the world the slates interbedded with tillites are generally interpreted as representing interglacial periods or temporary retreats of the ice. At least eight such changes of conditions of deposition are recorded in the Colfax rocks.

The strongest indications found of the action of ice are phenomena which are usually referred to the agency of ground-ice. The isolated boulders in the slaty beds are rather strongly indicative of the kind of rafting which is, with much reason, attributed to the floating action of icebergs or of river-ice. No other agency seems to account satisfactorily for the appearance of sporadic rounded boulders in such fine-grained sediments. The presence of ground-ice of course implies less rigorous climatic conditions than are entailed in the assumption of extensive glaciation. Average temperatures somewhat below the freezing point of water would be required only during the winter months to produce river-ice in sufficient abundance to account for the transportation of the erratic material observed in the Mariposa slates.

Should future investigations reveal positive evidence of glacial action within the Mariposa breccias, then the sporadic, disconnected areas of the coarse detrital material may well be explained by the rafting action of icebergs.

The second hypothesis proposed for the origin of the beds postulates the bounding of the structural troughs, which admitted the late Jurassic sea to the region, by rifts or abrupt monoclinal folds which presented fronts of high relief toward the basins of accumulation. Early Jurassic streams of low grade may be inferred, since the region was in the zone of erosion throughout Pennsylvanian and Triassic time. Some of these streams would doubtless maintain their courses across the structure imposed in the late Jurassic; it is these antecedent streams as well as the subsequent-consequent streams, i.e., those following the trend of the structural troughs, which may be considered

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to have supplied the silty material that now forms the slates, and much of the less triturated clastic that is comprised in the sandstones. The lateral boundaries of the basins, presenting such bold relief, would be vigorously attacked by the forces of weathering and their shoreward slopes would furnish abundant rock-waste which, accumulating at their base, would spread out as alluvial fans, the outer margins passing well under the shallow waters of the adjoining arm of the sea. Weathering in a humid climate produces fine-grained material normally which approaches the texture of clay; if feldspathic rocks are being reduced, much kaolin may indeed be mixed with the sandy mass. Siliceous rocks however are apt to fracture into angular pieces, which in time of maximum precipitation, travel down the slope and become intermingled with the finer material produced more slowly; igneous rocks likewise tend to fracture and split into angular fragments, and they too become part of the growing fan. Rapidly growing high-grade consequent streams developed in the degradation of a steep front, soon cut back by headward erosion far enough so that material transported from the headwaters, by the time it has reached the lower courses, shows considerable rounding, while in times of freshet, subangular fragments are supplied in abundance. Here, then, is a mechanism which furnishes a heterogeneous mixture of coarse material grading from wholly angular to well rounded, with a silty to sandy matrix. Progressive subsidence of the floor of the basin of deposition must have occurred to accommodate the very considerable thickness of sediments. If this progressive lowering of the basin took place in stages, as, for example, by movements along a zone of faulting, or by intermittent down-folding on a monocline, the frequent alternations from coarse to fine sediments observed within the series are readily accounted for.

The conditions of deposition along the eastern margin of San Francisco Bay present helpful analogies with the conditions which may have existed during the filling up of the Mariposa troughs. A fault-zone, known as the Haywards Rift, separates a region of considerable relief from the comparatively low-lying plane upon which Berkeley is situated. Angular material is furnished by the rapid degradation of the Berkeley Hills, while the Sacramento-San Joaquin river systems supply the bay with the silty material which may in time become consolidated into shale or even slate. If the present land surface west of the fault-zone were lowered slightly below the bay-level, conditions would be realized in which fine material could mingle

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with coarse, and a series of beds, in every way similar to the Mariposa, would be laid down.

Great persistence on the original dip is not to be anticipated under such conditions, and several instances have been cited where the Mariposa breccias grade laterally into sandstone and slate. Since the dips are all high it has not been found possible to trace many of the beds into fine sediments. The lack of cross-bedding in the Mariposa series is not considered a serious objection to its estuarine origin under the conditions described, because it is under just such conditions that current action is at a minimum; tidal action being spread over a long shore line nearly equally, would not favor false stratification although the chief rôle in the intermingling of the differently derived sediments must be assigned to this agency.

The sporadic distribution of boulders through some of the slate members constitutes the most serious objection to an hypothesis of origin involving alluviation; their presence must be accounted for in some other way. The alternate hypothesis of ground-ice transportation is the only one which suggests itself as reasonably accounting for this uncommon distribution.

The assumption of rifting or monoclinal folding as the agency which outlined the Mariposa basin is not violent in the light of later events in the history of the Sierra Nevada. That lines of weakness existed in the earth's crust in this region, trending in the same general direction, is abundantly witnessed by the great shearing-stresses that imposed a slaty cleavage on the rocks at the close of the Jurassic.

STRUCTURE

The Mariposa beds, in the area studied, have a structure imposed upon them which in detail is complicated, but which in its broad features is comparatively simple. The beds have been folded into a series of anticlines and synclines due to compressional forces acting in a northeast-southwest direction. The general strike of the structure is northwest-southeast.

The folding does not seem to have been as intense in the northern part of the belt as in the southern. The dips are gentler and the folds are more open in the vicinity of Colfax. In the Live Oak Ravine-Bunch Cañon section (sec. *K L M*, pl. 29) it is very difficult to make out the position of the several folds since the whole series has been closely compressed and overturned; a careful measurement of dip changes affords the only method of deciphering the structure here; even at

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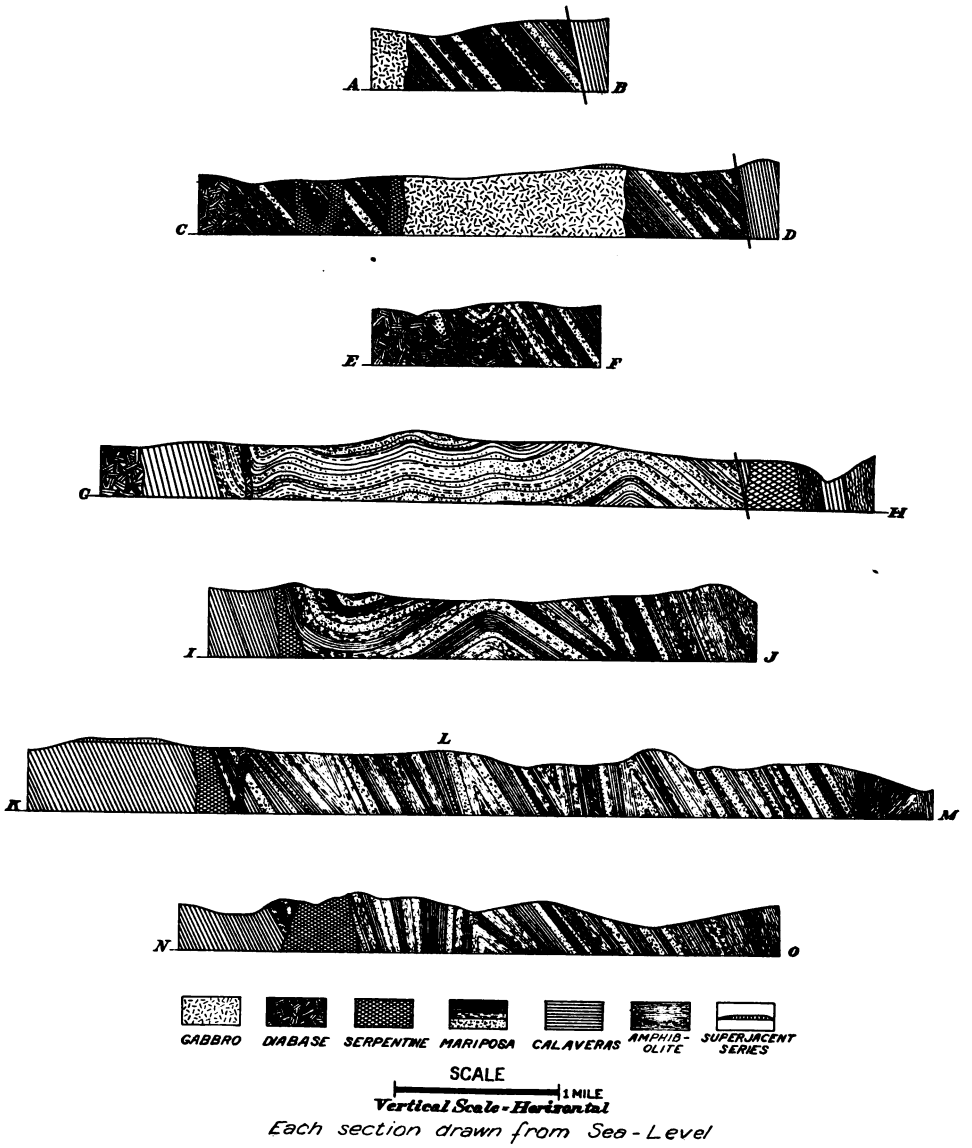

Structural sections

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best a high degree of accuracy cannot be attained. In the more open folds exposed along the Bear River and in the railroad cuts south of Colfax comparatively little difficulty of this nature is experienced. The approximate structural relations are shown in the seven sections on plate 29.

A fault is indicated in the sections but has not been placed upon the map. The long straight contact north of Cape Horn most certainly represents a dislocation of some magnitude. In the Colfax folio, Lindgren[32] states that the angular discordance at this contact is due to an unconformity, but since the younger beds are truncated by the contact plane (see secs. *AB, CD, GH*) their present position can be due only to a fault. No crushing is to be seen at the contact but this does not seriously weaken the evidence for the existence of the dislocation.

Faulting within the Mariposa itself is locally abundant but large dislocations were not recognized. Three well-defined minor faults affecting the slates were observed in a railroad cut one mile south of Colfax. In the creek east of Colfax a marked discordance of dip occurs in the slate; nearly horizontal beds are seen lying on the upturned jagged edges of the lower strata, with considerable kataclastic matter intervening.

The slaty cleavage that now characterizes the Mariposa beds was superposed on an already folded system of rocks. That this is true is proved by the not infrequent occurrence of planes of slaty cleavage cutting the original bedding planes. This phenomenon was observed only in the slate; the sandstone and breccia members always conform to the shearing planes. Figure 3 shows the slaty cleavage almost normal to the planes of sedimentation.

Viewed broadly the Mariposa rocks are to be considered as unconformably overlying the Calaveras and infolded with them in the great diastrophic paroxysm that affected the region at the close of the Jurassic. Evidence of structural unconformity is, however, hard to discover in the field. The western contact is obscured by debris north of Howell Hill, and south of this point a serpentine dike has appeared between the two formations. The eastern contact is regarded as a fault and the northern limit is an irruptive mass. When deformation is considered, however, the Mariposa rocks appear much younger than the Calaveras.

An exposure just east of Colfax station, at the south end of the

[32] Lindgren, W., U. S. Geol. Surv. Folio, no. 66.

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steep cliff facing west, may have an important bearing on the question of unconformity, and moreover, may in time furnish positive evidence supporting the glacial hypothesis. Here a chert body, containing radiolarian remains, and apparently belonging to the Calaveras series exposed to the west, is overlain by the breccia. If a depositional contact, this section shows profound erosion between the two formations. The general structure at this point is anticlinal, so that the chert may reasonably be explained as the basement upon which the Mariposa was laid down, now brought to the surface in the axis of the anticline. Professor Lawson and Professor Louderback with a party of graduate students from the University of California visited the locality and exposed a small area of the surface of the chert underlying the breccia in a search for evidence of glacial scouring. Three grooves were found, at least one of which was regarded by Professor Lawson as suggestive of ice sculpture, but as minor faulting has affected the whole region, positive evidence distinguishing the marks from slickenside phenomena was not obtained.

Angular discordance of dip is shown at the limestone outcrop already mentioned on Bear River, but its significance is probably not far-reaching. The Calaveras slates, which underlie the limestone bearing a Carboniferous fauna, have a north-south strike and a vertical dip; the Mariposa slates in the immediate vicinity strike northeast and southwest with dips ranging around sixty degrees. This small isolated area of Calaveras rocks is regarded by Lindgren[33] as representing a block torn loose from the main area at the time of the intrusion of the diabase which bounds the Mariposa to the northwest. Movements at this time might account for the discordance, hence the occurrence is not regarded as conclusive proof of angular unconformity.

The palaeontologic evidence of course indicates a profound break between the two formations, as does the occurrence of the abundant erosional debris of Calaveras rocks in the Mariposa.

Exact figures on the thickness of the Mariposa in the Colfax region cannot at present be given. In the columnar section shown in figure 2, however, a minimum of 2500 feet may be stated with some confidence, and the probability entertained that this estimate should be increased to 5000 feet. The possibility of a repetition at *R* has been mentioned. The amphibolite to the east is not to be considered the top of the formation; the contact may well be a pre-Tertiary fault. With the present data an upper limit of thickness is thus not assignable.

[33] Lindgren, W., U. S. Geol. Surv. Folio, no. 66.

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IGNEOUS ROCKS IN THE MARIPOSA

Dikes and masses of diabase and serpentine intrude the Mariposa formation at various localities, while a gabbro stock invades its northern limits. Their occurrence may be dismissed with the statement that little or no contact metamorphism has been induced in the sediments by their intrusion.

RÉSUMÉ

The Mariposa is a comfortable, gradational series of breccias, sandstones and slates, intruded by a gabbro mass in its northern limits. Structurally the beds have suffered isoclinal folding which, toward the north, becomes more open. Slaty cleavage parallels the bedding in the sandstone but frequently cuts the stratification planes of the slate.

All gradations occur in the sediments from fine mud up to masses a yard or more across. The coarser material is dominantly angular to subangular, although well rounded pebbles, chiefly quartz, do occur; the matrix is arenaceous to silty. The recognizable fragments could all have been derived from the associated Calaveras rocks.

Suggestions of glacial action or at least of the transporting agency of ground-ice or of icebergs appear in the sediments, but high grade streams consequent upon folding or faulting in a northwest-southeast direction, frequently rejuvenated by recurrent movements, may have provided the coarse material which makes up the breccia; and low grade streams, flowing longitudinally with respect to the Mariposa troughs, may have transported the fine detritus and more rounded pebbles, now forming a large part of the deposit.

The chief difficulties to be met in the way of a glacial hypothesis of origin are (*a*) lack of positive glacial evidence; (*b*) the large number of alternations of slate and breccia. Any normal process of alluviation, however, fails to explain the occurrence of sporadic pebbles and boulders in a silty matrix.

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EXPLANATION OF PLATE 30

Fig. A. Photomicrograph of finer facies of Mariposa breccia showing the predominance of angular material.

Fig. B. Photomicrograph of breccia showing rounding of some particles.

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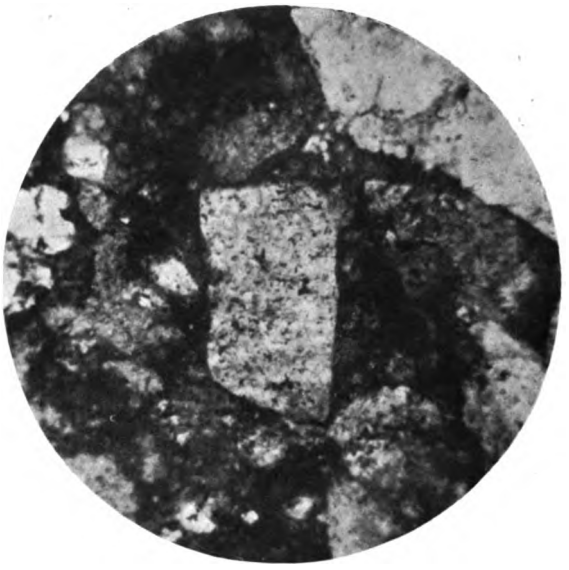

Fig. A

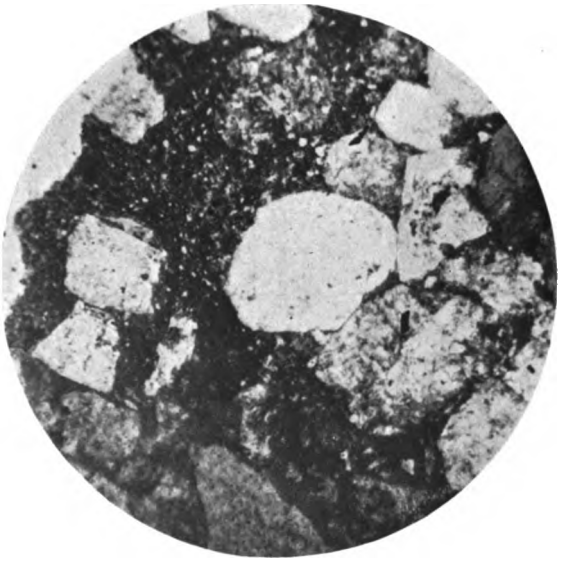

Fig. B

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EXPLANATION OF PLATE 31

Fig. A. Exposure of breccia in Bunch Cañon in which slate slabs occur in the finer clastic material.

Fig. B. A lenticular body of medium-grained breccia interbedded with slate on the Forest Hill road.

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Fig. A

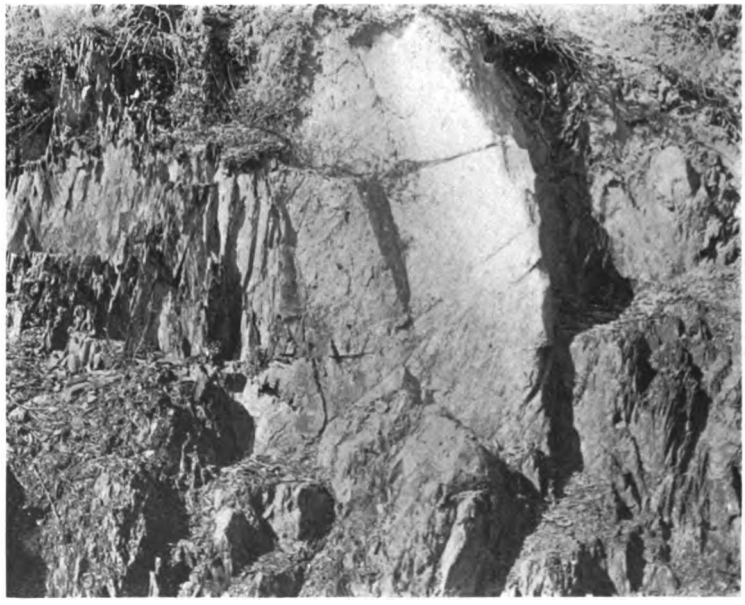

Fig. B

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EXPLANATION OF PLATE 32

Fig. A. A large boulder embedded in fine slate. The surface is scoured by the flood waters of the American River.

Fig. B. Another scoured surface in the American River Cañon showing fairly large sized blocks sparsely distributed through a slaty matrix.

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Fig. A

Fig. B

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EXPLANATION OF PLATE 33

Fig. A. Microphotograph of thin section of Mariposa sandstone.

Fig. B. Boulder of chert three feet in diameter embedded in an arenaceous slate. Railroad cut south of Colfax.

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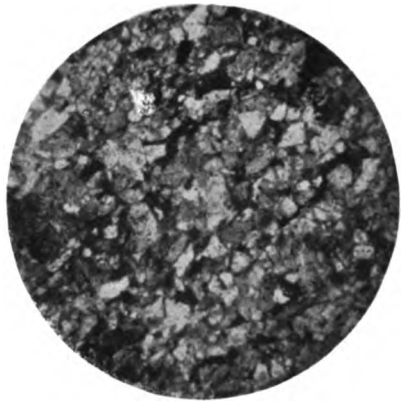

Fig. A

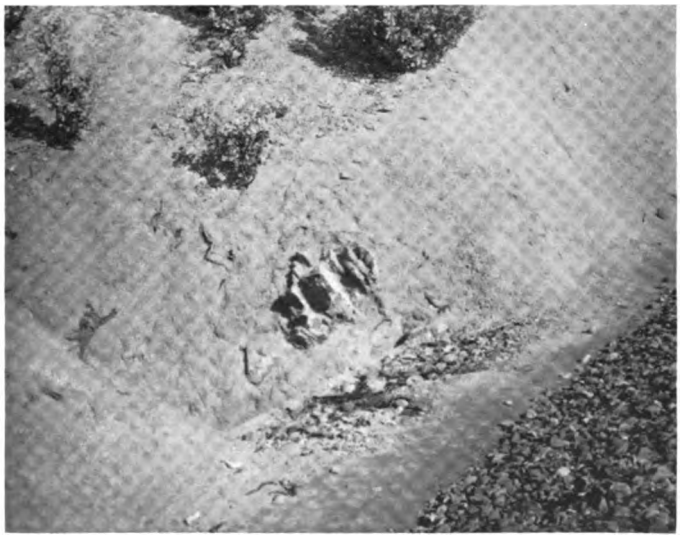

Fig. B

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BULLETIN OF THE DEPARTMENT OF
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Vol. 10, No. 22, pp. 421-443, 1 text-figure Issued November 16, 1917

RELATIONSHIPS OF PLIOCENE MAMMALIAN FAUNAS FROM THE PACIFIC COAST AND GREAT BASIN PROVINCES OF NORTH AMERICA

BY
JOHN C. MERRIAM

UNIVERSITY OF CALIFORNIA PRESS
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RELATIONSHIPS OF PLIOCENE MAMMALIAN FAUNAS FROM THE PACIFIC COAST AND GREAT BASIN PROVINCES OF NORTH AMERICA*

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INTRODUCTION

Much less than a decade ago the imperfection of our knowledge of North American Pliocene mammal faunas was so evident that it merited comment. Questions frequently arose concerning the relative paucity of mammalian remains and of formations representing this period, and explanation of the absence of Pliocene records included suggestion that the faunas had been largely described as Miocene or Pleistocene, or that conditions of relief had been unfavorable for accumulation of continental deposits.

As recently as 1909 Pliocene mammalian life known west of the Rocky Mountains was practically all comprised within seven more or less doubtfully determined species from the Rattlesnake Pliocene of

* Read before the Palaeontological Society, Albany, New York, December 27, 1916.

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the John Day Valley and several doubtful species from the imperfectly understood Idaho beds of Idaho. At that time the Great Plains Pliocene fauna included the Blanco of Texas, and the Republican River doubtfully referred to the same period. The Atlantic fauna consisted of the intermixed Alachua Pliocene and Peace Creek Pleistocene, and offered a serious problem in age determination by reason of this mixture.

Seven years ago description of the Snake Creek fauna, the richest of all American Pliocene mammal assemblages, by Matthew and Cook[1] gave the first definite indication of existence of an important Pliocene stage other than that of the Blanco. Immediately following the first study of the Snake Creek came discovery of the interesting Thousand Creek Pliocene fauna[2] of Nevada, with suggestion of similarity to the Nebraska Snake Creek in a number of peculiar types, especially in the presence of antelopes like those of the Old World Pliocene and Miocene. Following the discovery of the Thousand Creek there came to light on the western border of the continent the Ricardo fauna[3] of the Mohave Desert, the Etchegoin,[4] and the Pinole Tuff-Orinda[5] faunas of middle California, while the Rattlesnake fauna of eastern Oregon was increased to dimensions comparable to those of the Thousand Creek, Ricardo, and Blanco. Additional information regarding the composition and age of the interesting fauna of the Idaho formation in southwestern Idaho has also been obtained.

Through the work of Dr. E. H. Sellards,[6] the Alachua fauna of Florida has received valuable additions, and has had separated from it a considerable number of the elements of more modern aspect, which have heretofore confused interpretation of this assemblage.

Although at the present time American Pliocene mammal faunas are not as fully known as those of other Tertiary divisions, progress in accumulation and classification of material within the past five years has been relatively more rapid than for any other division of

[1] Matthew, W. D., and Cook, H. J., A Pliocene fauna from western Nebraska, Bull. Amer. Mus. Nat. Hist., vol. 26, pp. 361–414, 1909.

[2] Merriam, J. C., Tertiary mammal beds of Virgin Valley and Thousand Creek in northwestern Nevada, pt. 2, Vertebrate faunas, Univ. Calif. Publ. Bull. Dept. Geol., vol. 6, pp. 199–304, pls. 32–33, 1911.

[3] Merriam, J. C., Extinct faunas of the Mohave Desert: their significance in a study of the origin and evolution of life in America, Pop. Sci. Monthly, pp. 245–264, March, 1915.

[4] Merriam, J. C., Tertiary vertebrate faunas of the North Coalinga region of California, Trans. Amer. Philos. Soc., n. s., vol. 22, pt. 3, 44 pp., 1915.

[5] Merriam, J. C., Vertebrate fauna of the Orindan and Siestan beds in middle California, Univ. Calif. Publ. Bull. Dept. Geol., vol. 7, pp. 373–385, 1913.

[6] Eighth Ann. Rep. Florida Geol. Surv., pp. 92–100, 1916.

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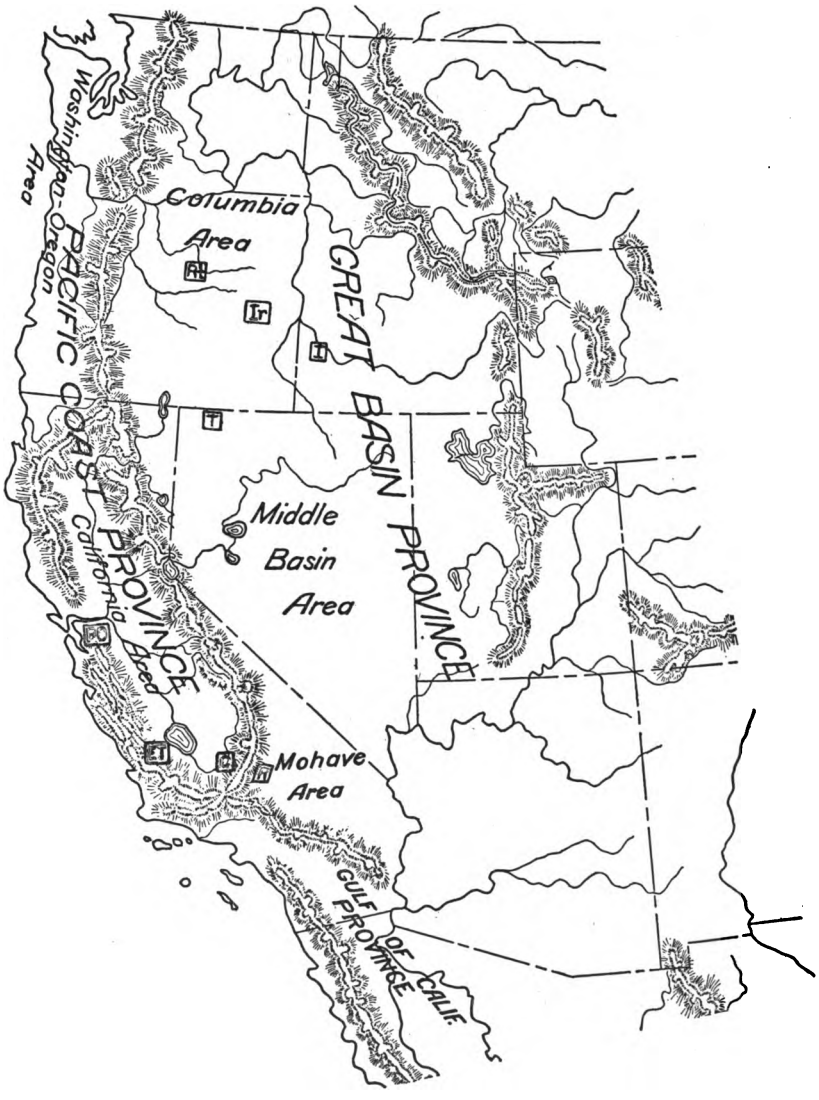

Fig. 1. Outline map illustrating principal occurrences of Pliocene mammal faunas in Tertiary provinces of that portion of United States west of the Wasatch Range. The most important localities are indicated as follows: I, Idaho beds; Ir, Ironside Pliocene; Rt, Rattlesnake; T, Thousand Creek; PO, Pinole Tuff-Orinda; ET, Etchegoin-Tulare; C, Chanac; R, Ricardo.

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the Cenozoic. We begin now to see for the first time the broader world relationships of our higher vertebrate Pliocene life.

Of American Pliocene faunas, those represented in the Pacific Coast and Great Basin provinces have been so imperfectly known that it seems desirable to present a general statement of their composition and relationships for use in consideration of certain fundamental faunal problems involved in later Cenozoic history.

AMERICAN PLIOCENE FAUNAS

Pacific Coast Province

At the present time there are known in the Pacific Coast province at least four important occurrences of Pliocene mammalian remains, and there are probably represented in these stations four fairly distinct stages or horizons. These are the upper and middle and lower Etchegoin on the western border of the San Joaquin Valley; the Tulare overlying the Etchegoin of the Great Valley of California; the Chanac formation of the Tejon Hills at the southern end of the San Joaquin Valley, and the Pinole Tuff-Orinda section of the Mount Diablo or San Francisco Bay region. Of these formations, the Etchegoin-Tulare section is not less than 10,000 feet in thickness; the Pinole Tuff-Orinda section represents at least 5000 feet of strata; the Tejon Hills section so far as known represents only a few hundred feet of accumulation.

The faunal sequence of the Pacific Coast region is exceptionally well represented in the *Etchegoin-Tulare section*, but the amount of material from the beds of that region is unfortunately scanty. Within the limits of the Etchegoin two or perhaps three faunal zones are known. There is apparently a clear distinction between the upper zone characterized by the presence of *Pliohippus proversus*, a very advanced horse like the Blanco *Pliohippus*, and the middle zone distinguished by the presence of *Pliohippus coalingensis*, a typical *Pliohippus*. Below the horizon of *P. coalingensis* several fragmentary specimens of *Hipparion* have been found, but as yet no remains of hipparions are known from the *P. coalingensis* and *P. proversus* zones. The lowest beds have been discussed in a tentative way as the *Hipparion* zone.

In the Tulare formation overlying the Etchegoin no certainly authenticated occurrences of mammalian remains are reported. About

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twenty years ago a specimen of *Hyaenognathus,* a peculiar dog like *Borophagus* of the Blanco Pliocene, was found associated with *Ischyrosmilus,* a machaerodont cat, near the town of McKittrick, in a formation now presumed to be Tulare.

The fauna of the Tulare-Etchegoin section on the western border of the San Joaquin Valley is as follows:

FAUNA OF TULARE-ETCHEGOIN SECTION

TULARE

†Hyaenognathus pachyodon Merriam
†Ischyrosmilus ischyrus (Merriam)

ETCHEGOIN

Pliohippus proversus zone
- Pliohippus proversus Merriam
- Camelops or Pliauchenia, sp.
- Procamelus?, sp.
- Cervus or Odocoileus, sp.
- Tayassu or Mylohyus?, sp.
- Mastodon
- Testudo?, sp.
- Undetermined fragmentary fish remains

Pliohippus coalingensis zone
- Pliohippus coalingensis (Merriam)
- Pliohippus?, sp., small
- Procamelus?, sp.
- Platygonus?, sp.

†Hipparion zone
- Neohipparion molle Merriam
- Neohipparion, sp.
- Protohippus or Pliohippus, sp.

In the *Pinole Tuff-Orinda section* scattered remains have been found at a number of localities, but the best representation of the fauna found at any one station is that secured from the Pinole Tuff and Orinda on the border of San Pablo Bay. In these strata there have been obtained the following forms:[7]

PINOLE TUFF-ORINDA FAUNA, SAN PABLO BAY

Pliohippus, near fairbanksi Merriam
Pliohippus, sp.
Rhinocerotid, near Teleoceras
Antelope, near Sphenophalos
Mastodontine form
Edentate, megalonychid
Tephrocyon, sp.
Testudinate remains

[7] From unpublished manuscript of Merriam and Stock.

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At localities in the Orinda, and in beds presumed to be higher than those of the horizons at San Pablo Bay, the following forms have been obtained:[8]

ORINDA FAUNA, CONTRA COSTA HILLS

Hipparion platystyle Merriam
Hipparion, near mohavense Merriam
Prosthennops, sp.
Procamelus, sp.
Pliauchenia, sp.
Tetrabelodon?, sp.
Dipoides lecontei (Merriam)

If any suggestion of sequence is given in the Pinole Tuff-Orinda section, it appears to be that *Hipparion* occurs at a horizon somewhat higher than that of the *Pliohippus* forms; but the stratigraphic succession is so imperfectly known that such a conclusion seems not at present to be fully warranted.

The *Tejon Hills fauna*[9] found in the Chanac formation at the southern end of San Joaquin Valley occurs in beds which rest upon marine San Pablo Upper Miocene, and are presumably unconformable upon that formation. The fauna includes the following forms:

CHANAC FAUNA

Protohippus tehonensis Merriam
Pliohippus, sp.
Hipparion gratum tehonense Merriam
Hipparion, near molle Merriam
Rhinocerotid, indet.
Prosthennops, sp.
Camelid, indet. large
Merycodus, near necatus Leidy
Proboscidean (Tetrabelodon?), sp.

In this fauna the hipparions are the most abundant forms. They represent two small species, one of which is very close to *Hipparion gratum* of the Great Plains region. The *Prosthennops* suggests the Pliocene species of the Great Valley of California. The *Merycodus* is near *necatus* Leidy, which appears both in the Barstow Upper Miocene and in the Ricardo Lower Pliocene of the Mohave Desert a few miles to the east.

Comparison of the Chanac fauna with the available Etchegoin and Tulare faunas shows that the Tejon Hills stage may be comparable

[8] Merriam, J. C., Univ. Calif. Publ. Bull. Dept. Geol., vol. 7, pp. 373–385, 1913.

[9] Merriam, J. C., Mammalian remains from the Chanac formation of the Tejon hills, California, Univ. Calif. Publ. Bull. Dept. Geol., vol. 10, pp. 111–127, 1916.

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to the Hipparion-bearing beds in the lowest portion of the Etchegoin section. The Pinole Tuff-Orinda fauna seems certainly older than the Pliohippus proversus zone of the Etchegoin. The fauna of the beds furnishing the best collections of the Pinole Tuff and of the lowest Orinda on San Pablo Bay is close to that of the Pliohippus coalingensis zone of the Etchegoin. The Tulare evidently represents the latest stage.

The sequence of Pliocene faunas and formations of the Pacific Coast province as we now know it is most satisfactorily expressed in a series of four stages. All four of these faunas may be present in one stratigraphic sequence in the North Coalinga region.

The stages are as follows:

Tulare	?Hyaenognathus zone
Upper Etchegoin	Pliohippus proversus zone
Middle Etchegoin	Pliohippus coalingensis zone
Lower Etchegoin or Chanac	Hipparion gratum tehonense or Hipparion molle zone

Great Basin Province

In the Great Basin region there are four important occurrences of Pliocene faunas. These are the Thousand Creek of the northern Nevada or Middle Basin area, the Ricardo of the Mohave Desert, the Rattlesnake of the John Day Valley, and the Idaho of southwestern Idaho.

The *Rattlesnake fauna* has unusual significance owing to exceptional clearness of stratigraphic relations of the beds in which it occurs. The Rattlesnake formation rests in marked unconformity in steep cliff section upon the Mascall, which contains a mammalian fauna of Middle or Upper Miocene age. Through the accumulated Rattlesnake deposits deep cañons have been cut, and in the lower reaches of these excavations are deposits containing a Pleistocene fauna. The age of the Rattlesnake formation is therefore limited on one side by a period of erosion and deformation succeeding accumulation of the Mascall Miocene, and on the other side by a period of erosion preceding accumulation of deposits of Pleistocene age.

Within the past field season a party from the Department of Palaeontology of the University of California has made intensive study of the Rattlesnake formation and fauna, and has increased the list of mammalian species considerably.

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The mammal forms now known from the Rattlesnake formation are the following:[10]

Rattlesnake Fauna

Carnivora
- ?Canis davisi Merriam
- Amphicyon, near amnicola Matthew and Cook
- Mustela, sp. *a*
- Mustela, sp. *b*
- Felis, large sp.
- Indarctos? oregonensis Merriam, Stock, and Moody

Edentata
- Megalonychid, gen. and sp. indet.

Rhinocerotidae
- ?Teleoceras fossiger (Cope)

Equidae
- Hipparion sinclairii Wortman
- Hipparion, near occidentale Leidy
- Hipparion, near anthonyi Merriam
- Pliohippus, near fairbanksi Merriam
- Pliohippus spectans (Cope)

Suidae
- Prosthennops, sp.

Camelidae
- Alticamelus altus (Marsh)
- Pliauchenia, sp.
- Procamelus, sp.

Antelopinae
- Sphenophalos, near nevadanus Merriam
- Ilingoceros?, sp.

Mastodontinae
- Tetrabelodon?, sp.

Rodentia
- Lepus?, sp.
- Dipoides?, sp.

Of the Rattlesnake horses, the best represented *Pliohippus* forms are much like those in the Pliohippus coalingensis zone of the Etchegoin, in the Thousand Creek, and in the Ricardo. The *Hipparion* species are like forms of the Thousand Creek and show some resemblance to a species from the Hipparion zone of the Pacific Coast province.

The Rattlesnake antelopes resemble those of the Thousand Creek fauna.

The *Thousand Creek fauna* is known from extensive exposures in the valley of Thousand Creek at the extreme northern border of Nevada. The stratigraphic relations of the Thousand Creek formation are unfortunately not as yet fully known, but there is every reason

[10] From unpublished manuscript of Merriam, Stock, and Moody.

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to consider that the beds are much later than those of the Virgin Valley Middle Miocene, which is of approximately the same facies as the Mascall Middle Miocene of the John Day region.

The fauna obtained in the Thousand Creek region is as follows:[11]

THOUSAND CREEK FAUNA

Reptilia
- Ophidian remains

Aves
- Branta, sp.

Insectivora
- Scapanus?, sp.

Carnivora
- Tephrocyon, near kelloggi Merriam
- Aelurodon, sp.
- Canis? davisi Merriam
- Ursus?, sp.
- Mustela furlongi Merriam
- Mustelid, indet.
- Taxidea nevadensis Butterworth
- Pseudaelurus, sp.
- Felis, sp. *a*
- Felis, sp. *b*

Rodentia
- Arctomys nevadensis Kellogg
- Arctomys minor Kellogg
- Citellus, sp.
- Aplodontia alexandrae Furlong
- Mylagaulus monodon (Cope)
- Dipoides, sp.
- Dipoides lecontei (Merriam)
- Entoptychus minimus Kellogg
- Peromyscus antiquus Kellogg
- Peromyscus?, sp.
- Diprionomys parvus Kellogg
- Diprionomys magnus Kellogg
- Hypolagus vetus (Kellogg)

Ungulata
- Pliohippus, near fairbanksi Merriam
- Hipparion, near occidentale Leidy
- Neohipparion leptode Merriam
- Teleoceras, near fossiger (Cope)
- Mastodon (Tetrabelodon?), sp.
- Pliauchenia?, sp.
- Camel, cf. Camelus americanus Wortman
- Prosthennops?, sp.
- Large suilline form
- Sphenophalos nevadanus Merriam
- Ilingoceros alexandrae Merriam
- Ilingoceros schizoceras Merriam

[11] Merriam, J. C., Univ. Calif. Publ. Bull. Dept. Geol., vol. 6, pp. 199–304, pls. 32–33, 1911; also Butterworth, E. M., Univ. Calif. Publ. Bull. Dept. Geol., vol. 10, pp. 21–24, 1916.

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The Thousand Creek fauna is characterized by the presence of numerous antelopes, some of which are presumably near the modern prong-horn, *Antilocapra*. Others show superficial resemblance to strepsicerine types of the Old World. The Thousand Creek fauna resembles that of the Rattlesnake in many respects. The horses are similar, and the only representation of the peculiar Thousand Creek antelopes known outside of the typical region are found in the Rattlesnake. The rarity of antelopes in the Rattlesnake may be due to chances of collecting, to difference in habitat, or to somewhat later age of the Thousand Creek beds.

Antelope remains found recently in the Pinole Tuff-Orinda fauna of San Pablo Bay suggest a relationship between the Thousand Creek-Rattlesnake and the Pinole Tuff-Orinda stage.

The *Ricardo fauna* of the Mohave Desert area is found in a formation comprising between 3000 and 5000 feet of sharply deformed strata situated at the eastern foot of the Sierra Nevada Range. The beds in which the fauna occurs consist in a large part of tuffs with desert conglomerates or fanglomerates and other deposits formed on land or in evanescent water bodies. In the thick Ricardo formation a moderate variation of the mammals is noticeable in comparison of different horizons, but the fauna seems to be a unit not divisible into sharply separated stages.

The species known from the Ricardo are as follows:

RICARDO FAUNA

Reptilia
- Testudo, sp.

Carnivora
- Canid, small
- Aelurodon, near wheelerianus, n. sp. *a*
- Aelurodon, n. sp. *b*
- Aelurodon, n. sp. *c*
- Aelurodon? or Tephrocyon, sp.
- Ischyrosmilus osborni, n. gen. and sp.
- Felid, large
- Felid, small, not Ischyrosmilus
- Mustela buwaldi, n. sp.

Rodentia
- Lepus?, sp.

Equidae
- Hipparion mohavense Merriam
- Hipparion mohavense callodonte Merriam
- Pliohippus tantalus Merriam
- Pliohippus fairbanksi Merriam
- Pliohippus, near mirabilis (Leidy)

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Proboscidea
  Tetrabelodon?, sp.
Oreodontidae
  Merycochoerus (Pronomotherium) californicus, n. sp.
Camelidae
  Procamelus, sp. *a*
  Procamelus, sp. *b*
  Pliauchenia, sp.
  Alticamelus?, sp.
Bovidae
  Merycodus, near necatus Leidy

In contrast with other Pacific Coast and Great Basin faunas the Ricardo is characterized by the presence of hipparions of an Old World type with *Pliohippus, Merycodus,* and an advanced oreodont near *Pronomotherium.* The Ricardo is in every respect a less advanced fauna than the Idaho. It is distinguished from the Thousand Creek-Rattlesnake stage by the presence of *Merycodus,* and an oreodont; by the presence of hipparions with round protocone rather than the *Neohipparion* type with flat protocone; and by absence of highly specialized antelopes and of rhinoceroses. The presence of such ancient types as *Merycodus* and an oreodont in the Ricardo indicates an earlier stage than Thousand Creek-Rattlesnake from which these types are absent. It is, moreover, possible that the Thousand Creek antelopes are descendants of the Ricardo *Merycodus.* Geologic evidence tending to support the age determination based upon palaeontologic data is found in the greater degree of induration and deformation of the Ricardo.

The *Idaho beds* of Oregon were named by E. D. Cope,[12] who described from them a considerable series of fishes. Beds referred to the Idaho extend over a large area bordering the Snake River Valley in southwestern Idaho, and presumably reach into southeastern Oregon. They are several hundred feet in thickness and exhibit a slight degree of deformation at certain localities. The beds are generally unconsolidated, but may show considerable induration and form steep cliffs. Lindgren[13] collected a mammalian fauna from exposures presumed to be of the same age as the Idaho of Cope. The remains obtained by Lindgren were determined as Pliocene by F. A. Lucas. In the summer of 1916 collections were made at a number of localities in this region by J. C. Merriam and J. P. Buwalda for the United States Geological Survey.

[12] Cope. E. D., Proc. Amer. Philos. Soc., Nov., 1870, pp. 538–547; also Proc. Acad. Nat. Sci. Phila., p. 125, June 26, 1883.

[13] Lindgren, W., 20th Ann. Rep. U. S. Geol. Surv., pt. 3, p. 99, 1900.

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The fauna reported from beds referred to the Idaho formation is as follows:

Fauna Referred to Idaho

Equus idahoensis, n. sp.
Equus excelsus? Leidy
Protohippus?
Rhinoceros, probably Aphelops (Teleoceras) fossiger (Cope)
Mastodon mirificus Leidy
Procamelus, size of P. major (Leidy)
Cervus, possibly new, slightly smaller and more slender than C. canadensis (Erxleben)
Horn-core of true antelope (Tragocerus?)
Ischyrosmilus, n. sp.
Morotherium leptonyx Marsh
Castor, possibly n. sp.
Olor, size of O. palaeocygnus
Graculus idahoensis Marsh

The Idaho formation is not as yet satisfactorily separated from the Payette Eocene or Miocene, and from a Miocene or Pliocene stage which may intervene between the Payette and the Idaho. It is, however, quite certain that there exists over a large area of southwestern Idaho a formation several hundred feet thick which may show evidence of deformation, and which contains a fauna of a stage representing either the latest Pliocene or the earliest Pleistocene.

Mammalian remains presumed to represent the Idaho have been reported from a number of localities of which the relative geologic position is uncertain. One might assume from the composition of the entire list of forms obtained by Lindgren that the collections are in the main from beds of Pliocene age, with the possibility that some of the elements are derived from Pleistocene deposits, and possibly some from horizons older than typical Idaho.

Of the several mammalian types listed by Lindgren, the horses are undoubtedly the most important for palaeontologic determination of age. The only form specifically determined in the earlier collections was one considered by Leidy to represent *Equus excelsus*. This species is not known from beds older than Pleistocene. Bones from near Sommercamp Ranch, in the northern portion of the Silver City quadrangle, have been referred to *Protohippus*. If this determination is correct, these beds might be Pliocene or late Miocene. Horse remains obtained at Idaho localities by Buwalda and Merriam in 1916, in the course of investigations carried on for the United States Geological Survey, are of a type clearly to be referred to *Equus*. In the lowest beds examined at a locality on the Snake River, southwest of the town

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of Caldwell, the bottom of the section furnished material representing a very advanced equine form not distinguished from *Equus* on the basis of size or of advance in specialization of feet and teeth. This species does not seem to the writer specifically identical with any thus far described in America. It differs from the *Pliohippus proversus* type of the upper Etchegoin Pliocene in the typical equine character of the upper cheek-teeth, as shown by the inner wall of the protocone, the fossettes, and the outer walls of the paracone and metacone; so that it must be included within the genus *Equus*. On the other hand, it differs from the described Pleistocene forms of *Equus* in the shorter protocone, which approaches the type of pillar in *Equus stenonis* of the Old World Pliocene.

A rhinoceros from exposures considered as Idaho, east of Boise, was referred to *Aphelops* (*Teleoceras*) *fossiger*. This form represents the late Miocene or Pliocene. *Mastodon mirificus* determined by Leidy from a specimen obtained by Clarence King on Sinker Creek is a Pliocene type. The remains of *Procamelus* might be Miocene or Pliocene. Horn-cores of antelopes, obtained with rhinoceros material near Boise, represent a Tragocerus-like type known in America only from beds of Pliocene age. *Castor* is known from the upper Etchegoin of the western border of the San Joaquin Valley in California. A very large machaerodont cat found in an Idaho exposure on the Snake River southwest of Caldwell belongs to a type nearest to *Ischyrosmilus,* presumed to represent the Tulare stage in Calfornia.

With our available knowledge of the mammalian fauna of the Idaho, determination of this formation as Pliocene is apparently supported, but beds both older and younger than Pliocene may be included in the localities from which material has been secured. It is highly desirable to have careful collecting work carried on by trained investigators in the bad-land deposits over the entire area presumed to represent the Idaho formation.

Compared with other faunal assemblages referred to the Pliocene of the Great Basin province, the Idaho fauna of the best known locality in the Snake River region exhibits a relatively advanced stage. The horses find their nearest relatives in the Pleistocene and in the Pliohippus proversus zone of the Upper Etchegoin Pliocene. The deer of the Idaho are possibly related to those of the Upper Etchegoin. The cat is nearest to the ?Tulare *Ischyrosmilus*. The Idaho stage is evidently later than any other described Pliocene faunal zone of the Great Basin province.

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The Pliocene faunas of the Great Basin region clearly represent at least three quite distinct stages: the Ricardo, the Rattlesnake and Thousand Creek, and the Idaho. The Ricardo fauna, including as it does *Merycodus,* an oreodont, and several other forms of middle Cenozoic type, is certainly older than the Thousand Creek, Rattlesnake, and Idaho, in which these forms do not appear.

The Thousand Creek and Rattlesnake are evidently of approximately the same stage. In neither fauna is *Merycodus* represented, and no oreodont remains are known. The antilopine type represented by *Merycodus* in the Ricardo is expressed in various forms of *Sphenophalos* and *Ilingoceros.* The hipparions of the Rattlesnake and Thousand Creek are apparently a more advanced stage than those of Ricardo, and incline toward the *Neohipparion* rather than the *Hipparion* type.

If, as seems necessary, the Idaho fauna be included in the Pliocene, it must be considered as representing a much later epoch than any of the other Great Basin stages. The presence of *Equus* and *Cervus* and the absence of *Pliohippus* indicate a stage verging on the Pleistocene.

The three Pliocene stages of the Great Basin province may be arranged as follows:

Idaho	Equus-Cervus? zone
Thousand Creek-Rattlesnake	Sphenophalos-Neohipparion zone
Ricardo	Hipparion-Merycodus zone

GREAT PLAINS PROVINCE

In the Tertiary deposits of the Great Plains region a much larger representation of the Pliocene mammal fauna is found than has been thus far secured in the provinces west of the Rocky Mountains. Two or three occurrences of unusual importance are known and at least two faunal stages are distinguished.

The *Blanco fauna* described by Cope[14] from Texas is the most advanced of the well known Great Plains faunas, and the stratigraphic relations of the beds so far as known indicate Pliocene age.

The list of forms in the Blanco fauna is as follows:

BLANCO FAUNA

Carnivora
- Borophagus diversidens Cope
- ?Amphicyon, sp.
- Canimartes cumminsi Cope
- Felis hillanus Cope

[14] Cope, E. D., A preliminary report on the vertebrate palaeontology of the Llano Estacado, 4th Ann. Rep. Texas Geol. Surv., 136 pp., 23 pls., 1893.

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Edentata
- Glyptotherium texanum Osborn
- Megalonyx leptostomus Cope

Proboscidea
- Trilophodon? (Gomphotherium) shepardii Leidy
- Dibelodon (Stegodon) mirificus Leidy
- ?Dibelodon tropicus Cope
- ?Dibelodon praecursor Cope
- ?Dibelodon humboldtii (Cuvier)

Equidae
- Pliohippus simplicidens (Cope)
- Protohippus?, minutus (Cope)
- Pliohippus cumminsii (Cope)
- Neohipparion, sp.

Dicotylidae
- Platygonus bicalcaratus Cope
- Platygonus texanus Gidley

Camelidae
- Pliauchenia spatula Cope
- Pliauchenia, sp.

Characteristic of the Blanco is the presence of advanced horses of the most progressive type of *Pliohippus* with *Neohipparion,* of advanced mastodontine types near *Stegodon,* of very advanced dogs of the *Borophagus* type, and of two types of edentates. This fauna is also characterized by absence of oreodonts and rhinoceroses.

Most important of all Pliocene mammal assemblages of America is the *Snake Creek* fauna[15] of western Nebraska obtained from beds considered to represent a part of the Ogallalla formation of Darton. From this formation over seventy species are known at present and the wealth of material leads one to hope that the number may be further increased by future collecting.

The varied fauna of Snake Creek may be listed as follows:

SNAKE CREEK FAUNA

Dogs
- Amphicyon amnicola Matthew and Cook
- Amphicyon, sp. indet.
- ?Amphicyon, sp. indesc.
- Aelurodon haydeni validus Matthew and Cook
- Aelurodon saevus secundus Matthew and Cook
- Aelurodon, cf. wheelerianus Cope
- Aelurodon, sp. div. indet.
- Tephrocyon hippophagus Matthew and Cook
- Tephrocyon, cf. temerarius Leidy
- Canis, cf. vafer Leidy

[15] Matthew, W. D., and Cook, H. J., Bull. Amer. Mus. Nat. Hist., vol. 26, pp. 361–414, 1909; Sinclair, W. J., Additions to the fauna of the Lower Pliocene Snake Creek beds (results of the Princeton University 1914 expedition to Nebraska), Proc. Amer. Philos. Soc., vol. 54, pp. 73–95, 1915.

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Tephrocyon mortifer Cook
Tephrocyon, sp. maj.
†Cyon, sp.

Civet-cat
Bassariscus antiquus Matthew and Cook

Mustelines
Brachypsalis pachycephalus Cope
Brachypsalis obliquidens Sinclair
Martes glareae Sinclair

Cats
Pseudaelurus, near intrepidus Leidy
Cat, non-machaerodont
Machaerodont cat, gen. indet.
†Felis, cf. maximus Scott and Osborn

Rodents
Mylagaulus, cf. monodon (Cope)
Dipoides curtus Matthew and Cook
Dipoides tortus (Leidy)
Hystricops, cf. venustus Leidy
Geomys, cf. bisulcatus Marsh

Edentates
Megalonychid, gen. et sp. indet.

Rhinoceroses
Teleoceras, sp.
Aphelops, sp.
†Caenopus, sp.

Horses
Archaeohippus, sp.
Parahippus, cf. cognatus Leidy
Hypohippus, cf. affinis Leidy
Hypohippus, sp.
Merychippus, cf. insignis Leidy
Merychippus, close to calamarius (Cope)
Hipparion, cf. occidentale Leidy
Hipparion gratum Leidy
Hipparion, cf. affine Leidy
Protohippus, cf. placidus Leidy
Protohippus, near perditus Leidy
Pliohippus, cf. mirabilis (Leidy)
Pliohippus, sp. div.

Peccaries
Prosthennops, cf. crassigenis Gidley
Prosthennops, sp.

Oreodonts
Merychyus (Metoreodon) relictus Matthew and Cook
Merychyus (Metoreodon) profectus Matthew and Cook
Merychyus (Metoreodon), sp.
Pronomotherium siouense Sinclair

Camels
Protolabis princetonianus Sinclair
Pliauchenia (Megatylopus) gigas Matthew and Cook
Alticamelus procerus Matthew and Cook

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Alticamelus, sp. div.
?Procamelus, sp. div.
Antelopes and deer
Dromomeryx whitfordi Sinclair
Drepanomeryx falciformis Sinclair
Cervus, sp.
Blastomeryx elegans Matthew and Cook
Blastomeryx, cf. wellsi Matthew
Merycodus necatus sabulonis Matthew and Cook
Merycodus, cf. necatus Leidy
Merycodus, sp. div.
Bovids
Neotragocerus improvisus Matthew and Cook
Bovid, gen. indet.
Bison, sp.
Mastodons
Gomphotherium, sp.
?Mastodon, sp.
Birds
Aquila dananus? Marsh
Buteo, near borealis (Gmelin)
Reptiles
Crocodile vertebra
Lizard jaws
Huge land tortoise
Of uncertain position
Part of large mammal jaw

The Snake Creek fauna is characterized by the presence of advanced types of *Pliohippus, Neohipparion,* antelopes of the *Tragocerus* type, *Aelurodon,* and a rare edentate. From Snake Creek are also obtained less advanced forms as *Protohippus, Merychippus, Aphelops, Dromomeryx, Blastomeryx, Merycodus,* two or more oreodonts, and *Tephrocyon.* The stage of the most progressive horses approaches that of the Blanco forms, while abundant material represents *Merychippus* types nearly identical with those of the Upper Miocene.

The fauna as a whole seems older than the Blanco. If it should ever appear to be divisible into several horizons, one stage may be found near that of the Thousand Creek and somewhat older than Blanco. Another stage might be near the boundary line between Miocene and Pliocene.

The *Republican River* fauna of northwestern Kansas, which is often tentatively referred to the lowest Pliocene, is an important assemblage of forms evidently older than the Snake Creek and containing a number of rather characteristic Miocene types. The faunal list is as follows:[16]

[16] Adapted from Osborn, H. F., and Matthew, W. D., U. S. Geol. Surv. Bull. 361, pp. 115–118, 1909.

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REPUBLICAN RIVER FAUNA

Aelurodon saevus (Leidy)
Aelurodon wheelerianus (Cope)
Dinocyon maeandrinus Hatcher
"Machaerodus" catocopis Cope
?Machaerodus crassidens Cragin
Cynomys, sp.
Dipoides tortus (Leidy)
Mylagaulus sesquipedalis Cope
Mylagaulus monodon Cope
Epigaulus hatcheri Gidley
Lepus, sp.
Tetralophodon euhypodon (Cope)
Tetralophodon campester (Cope)
Teleoceras fossiger (Cope)
Peraceras superciliosus Cope
?Aphelops malacorhinus Cope
Hypohippus, sp.
Protohippus profectus Cope
?Neohipparion retrusum (Cope)
Prosthennops serus (Cope)
?Merycochoerus, sp.
?Merychyus, sp.
?Procamelus prehensilis (Cope)
Procamelus, sp. div.
Pliauchenia minima Wortman
Pliauchenia, sp. max
Merycodus, sp.

The presence in the Republican River of *Mylagaulus, Aphelops, Merycodus,* and several oreodonts strongly suggests Miocene age. *Aelurodon wheelerianus* is much like the common *Aelurodon* from the Barstow. Other forms as *Dipoides* and *Neohipparion* are Pliocene types. Matthew and Cook consider this fauna older than Snake Creek, and it is evidently near the border line between Miocene and Pliocene.

The *Loup River*[17] or *Nebraska formation* of Nebraska contains a fauna which has certain Pliocene types as *Dibelodon* (*Stegodon*) *mirificus,* and possibly *Hipparion,* apparently of the same horizon with *Equus* and *Elephas.* This assemblage represents a stage near that of the Idaho or Tulare, or perhaps somewhat later. More information is necessary before a judgment as to the composition and age of this fauna can be given.

Of the several Great Plains faunas there can be no doubt as to relative position of the two elements of largest importance: the Blanco is clearly younger than the Snake Creek. If the Loup River is Pliocene it is evidently younger than the Blanco, and if the Republican River fauna be included in the Pliocene it is older than Snake Creek. The sequence then appear as follows:

??Loup River	Equus-Elephas zone
Blanco	Pliohippus simplicidens-Boraphagus zone
Snake Creek	Hipparion-Tragocerus zone
?Republican River	Peraceras-Protohippus zone

ATLANTIC PROVINCE

In the region east of the Mississippi, Pliocene mammal remains sufficient to constitute a basis for study are known in the Alachua

[17] Leidy, J., Extinct Mammalian Fauna of Dakota and Nebraska, pp. 13 and 255, 1869.

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beds of Florida. The study of the fauna has been difficult because of mixture with remains from other formations. The recent work of Dr. E. H. Sellards[18] has made possible segregation of the Pliocene elements. The list is as follows:

ALACHUA FAUNA

Alachua Clays and Bone Valley

Teleoceras fossiger var. proterus (Leidy)
Aphelops malacorhinus Cope
?Mammut progenium Hay
Mastodon (Trilophodon) floridanus Leidy
Hipparion ingenuum (Leidy)
Hipparion plicatile Leidy
Hipparion minor Sellards
Procamelus major (Leidy)
Procamelus medius (Leidy)
Procamelus minor (Leidy)
Tomistoma americana Sellards
Alligator
Cetacean
Fishes
Odocoileus
Megatherium, sp.
Agriotherium schneideri Sellards
Emys
Crocodile or alligator
Garfish

Dunnellon Formation

Aphelops malacorhinus Cope
Mastodon (Trilophodon) floridanus Leidy
Hipparion, sp. div.
Parahippus, sp.
?Megalonyx, sp.
Ursus, sp.
Felis, sp.
Odocoileus, sp.
Procamelus minor (Leidy)

Newberry, Alachua County, Possibly Pleistocene

Equus littoralis Hay
Odocoileus, sp.
Tapirus terrestris (Linn.)

TIME RELATIONS OF AMERICAN FAUNAS

Comparison of Pacific Coast and Great Basin Pliocene faunas shows that of the four stages in the Pacific Coast province the uppermost, the Tulare or Hyaenognathus zone, is evidently nearest the Idaho or Equus-Cervus? zone of the Great Basin. As yet these two faunas are too imperfectly known to permit satisfactory comparison.

The second or Pliohippus proversus zone of the Pacific Coast upper Etchegoin is a less advanced stage than the Idaho, but the fauna is quite different from that of the Thousand Creek-Rattlesnake stage, and is more advanced. This zone is not as yet known in the Great Basin province.

The Pliohippus coalingensis zone of the Pacific Coast region con-

[18] Sellards, E. H., Fossil vertebrates from Florida: A new Miocene fauna; New Pliocene species; The Pleistocene fauna, 8th Ann. Rep. Florida Geol. Surv., pp. 79–119, pls. 10–14, 1916.

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tains horse types near those of the Rattlesnake-Thousand Creek stage and is of approximately the same age.

The Chanac Hipparion gratum tehonense stage of the Pacific Coast province is nearest to the Ricardo of the Great Basin, but not necessarily identical with it.

The relationship of the Pacific Coast and Great Basin Pliocene sequences is approximately as shown in the table on page 443.

Comparison of the series of Pliocene mammal faunas of the Great Basin-Pacific Coast scale with that of the Great Plains and Atlantic provinces should not be expected to show a large percentage of common specific types, even if the time of deposition be approximately identical, as important physical barriers intervened and specific range would presumably not be much wider in America of the Pliocene than at present.

In a comparison of the Great Plains sequence with that in the provinces west of the Wasatch there is noticeable at once a similarity of the Blanco and Upper Etchegoin horses, and of the Blanco canid of the *Borophagus* type and *Hyaenognathus* presumed to be of Tulare age. There seems good reason for considering the Blanco and Upper Etchegoin faunas as of nearly the same stage. The Tulare, which immediately follows the Upper Etchegoin, may approximate a late stage of the Blanco.

The Snake Creek fauna of western Nebraska contains a considerable number of forms corresponding approximately to those of the Ricardo stage of the Great Basin province. The Snake Creek horses include species of *Pliohippus* and *Hipparion* at least as advanced as those of the Ricardo. The artiodactyls of the Snake Creek include *Merycodus* and advanced oreodont forms as in the Ricardo. With the advanced horses there are, however, noted certain primitive forms as *Merychippus* and *Parahippus*, and with artiodactyls of the *Merycodus* type some advanced antelopes are also represented. If, as seems possible, the Snake Creek fauna represents more than one stage, it is to be presumed that one of the horizons is not far from the stage of the Ricardo. It is possible that another horizon in the Snake Creek beds might correspond to the stage of the Rattlesnake, Thousand Creek, and Middle Etchegoin.

The Republican River fauna of northwestern Kansas represents a stage recognized as near the beginning of the Pliocene. Matthew and Cook,[19] who have made a most careful comparison of this assemblage

[19] Matthew, W. D., and Cook, H. J., Bull. Amer. Mus. Nat. Hist., vol. 26, p. 368, 1909.

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with the Snake Creek, consider that modernization is more apparent in the latter. The Republican River canid fauna contains only advanced forms of the *Aelurodon* or *Dinocyon* type. The Equidae include *Hypohippus, Protohippus,* and *Neohipparion.* Two oreodonts, *Merycochoerus* and *Merychyus,* are present with camels of the genera *Procamelus* and *Pliauchenia. Dromomeryx* and *Blastomeryx* are not represented. Considering that the two areas discussed are widely separated geographically, it would seem to the writer that the Republican River is not far from the stage of faunal evolution shown by the Ricardo. If the Ricardo is younger than the Snake Creek, the judgment of Matthew and Cook, suggesting the situation of the Republican River earlier rather than later than the Snake Creek, necessitates placing the Republican River somewhat below the Ricardo.

Relationship between the fauna of the Ricardo and that of the Alachua beds of Florida is suggested especially by similarity of the *Hipparion* species. The American forms most resembling the Ricardo hipparions are *H. plicatile* and *H. ingenuum* of the Alachua beds and *H. venustum* from Ashley River, South Carolina. This resemblance may be purely incidental, but possibly indicates a close genetic relationship. J. W. Gidley[20] has suggested that the Florida hipparions are like those of the true Old World *Hipparion* type with round protocone. It is possible that the Alachua and Ricardo *Hipparion* forms represent some of the oldest members of this group in America, these species having survived in the southeast and southwest corners of the continent after the forms with round protocone had disappeared in the middle regions of the continent.

As has been known, there is a marked resemblance between the Alachua fauna and the life of the Republican River and Snake Creek stages. The Alachua appears more advanced than the Republican River and approaches the Snake Creek more closely in the important *Hipparion* elements. The presence of both *Teleoceras* and *Aphelops* in the Alachua indicates affinities with the Miocene. The recently described *Mammut progenium* and *Agriotherium* (*Hyaenarctos*) indicate with considerable definiteness the Pliocene rather than Miocene aspect of the Alachua.

[20] Gidley, J. W., Revision of the Miocene and Pliocene Equidae of North America, Bull. Amer. Mus. Nat. Hist., vol. 23, pp. 905–906, 1907.

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CORRELATION WITH OLD WORLD FAUNAS

Certain elements found in American Pliocene mammal faunas so closely resemble characteristic genera and even species of the Old World that little doubt exists concerning their common origin. Such types as *Hipparion, Teleoceras, Tragocerus, Hyaenarctos, Ischyrosmilus, Pseudaelurus,* and *Dipoides* appear even in similar specific garb at various localities in the Pliocene of America, Asia, and Europe. It is worthy of note that the forms appearing in America and in the Old World are also generally widely spread on each of these two areas, indicating their tendency to range widely. It is also worthy of note that some of these forms have a long antecedent history in one area and appear suddenly in the Pliocene of the adjacent region, while within approximately the same periods other groups originating in the second region extended their range to the first area. These arguments, taken with the facts relating to corresponding amount of organic evolution and corresponding amount of crustal movement in both regions, leave little room for doubt that we have here an unusually well founded case of correlation in which contemporaneity is indicated, at least within the limits of half of a geological period.

There is good reason to believe that the earlier American Pliocene faunas as the Alachua, Snake Creek, Ricardo, Rattlesnake, and Thousand Creek are approximately contemporaneous with Old World faunas of Schansi in China, Dhok Pathan of India, Maragha of Persia, and Pikermi of Greece. It is not yet possible to give an exact comparison of the relative stages of the early Pliocene represented by these faunas. For the later Pliocene less evidence of contemporaneity of American and Old World faunas is available, but there is good reason for looking carefully into the question of relative stage of the Idaho and the Boulder Conglomerate of India, both possibly in part Pleistocene, and both containing primitive forms of *Equus.*

Future work will largely illuminate the field of investigation covering Pliocene life, upon which we have as yet made only a beginning; and later years of study hold in store much of that unequalled pleasure found in difficult scientific quest, and in the discoveries which so frequently reward intensive investigation.

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APPROXIMATE TIME RELATIONS OF TYPICAL PLIOCENE MAMMAL FAUNAS OF NORTHERN HEMISPHERE

NORTH AMERICAN PROVINCES				OLD WORLD OCCURRENCES			
PACIFIC COAST	GREAT BASIN	GREAT PLAINS	ATLANTIC	CHINA	INDIA	PERSIA	EUROPE
	Idaho Equus Ischyrosmilus Cervus?	??Loup River Equus Elephas			Boulder Conglomerate Equus Elephas Camelus		Val d'Arno Equus Elephas
Tulare ?Hyaenognathus ?Ischyrosmilus		Blanco Borophagus Plioh. simplicidens					
Upper Etchegoin Plioh. proversus Cervus?					Pinjor Hipparion Stegodon		?Montpellier Hyaenarctos
	Thousand Creek–Rattlesnake Pliohippus Hipparion Teleoceras Ilingoceros Indarctos						
Middle Etchegoin Plioh. coalingensis		Snake Creek Pliohippus Hipparion Tragocerus			Tatrot Hipparion Stegodon		
							?Casino Palaeoryx
				Schansi, Honan, etc. Hipparion		Maragha Hipparion Tragocerus Palaeoreas	
			Alachua Hipparion Teleoceras Procamelus Hyaenarctos	Hypohippus? Tragocerus Palaeoreas Hyaenarctos?	Dhok Pathan Hipparion Teleoceras Tragocerus Strepsicerine antelope		Pikermi Hipparion Tragocerus Palaeoreas Hyaenarctos
Lower Etchegoin (Jacalitos) Chanac Hipparion Merycodus Protohippus	Ricardo Hipparion Pliohippus Merycodus Oreodont	?Snake Creek					
		Republican River Protohippus Hipparion					

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ANTICLINES NEAR SUNSHINE, PARK COUNTY, WYOMING

BY

C. L. MOODY and N. L. TALIAFERRO

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ANTICLINES NEAR SUNSHINE, PARK COUNTY, WYOMING

BY
C. L. MOODY AND N. L. TALIAFERRO

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LOCATION

The area described in this report lies in Townships 46, 47, and 48 N, Range 101 W, along the western edge of the Bighorn Basin and in the southeastern part of Park County, Wyoming. All but that

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portion of the area south of Redtop Mountain is included in the southwestern part of the Meeteetse quadrangle.

The nearest railroad point is Cody, on a branch of the Chicago, Burlington and Quincy Railroad. Sunshine postoffice, fifty miles from Cody, may be reached by stage to Meeteetse, and thence by private conveyance (see fig. 1).

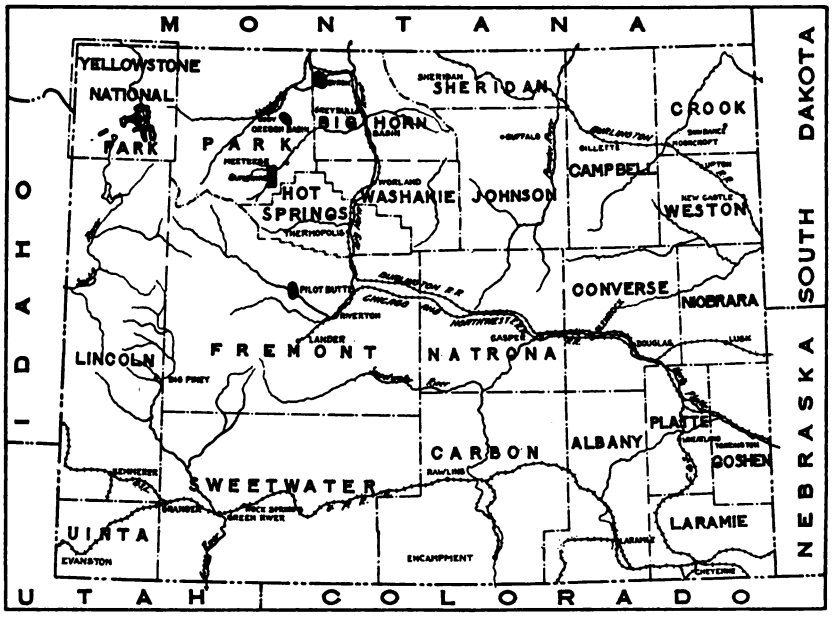

Fig. 1—Map of Wyoming, showing location of area described.

FIELD WORK

The field work on which this report is based was done in the early part of July, 1917. A part of the mapping was done directly on the Meeteetse sheet, while that part of the area south of this sheet was mapped with plane table and open sight alidade.

PREVIOUS WORK

The area covered by this report is included in the map accompanying C. A. Fisher's report on the Bighorn Basin. This map does not distinguish between the various formations of the Colorado group, nor does it show the details of the structure here described.

The following is a partial bibliography of the geology of the Bighorn Basin:

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Eldridge, G. H., A geologic reconnaissance in northwest Wyoming, U. S. Geol. Surv., Bull. 119, 1894.

Darton, N. H., Comparison of the stratigraphy of the Black Hills, Bighorn Mountains and Rocky Mountain Front Range, Bull. Geol. Soc. Am., vol. 15, pp. 379–448, 1904.

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Darton, N. H., Preliminary report on the geology and underground resources of the central Great Plains, U. S. Geol. Surv., Professional Paper no. 32, 1905.

——, Geology of the Bighorn Mountains, U. S. Geol. Surv., Professional Paper no. 51, 1906.

Fisher, C. A., Geology and water resources of the Bighorn Basin, U. S. Geol. Surv., Professional Paper no. 53, 1906.

——, Mineral resources of the Bighorn Basin, U. S. Geol. Surv., Bull. 285, pp. 311–315, 1906.

Washburne, C. W., Gas fields of the Bighorn Basin, Wyoming, U. S. Geol. Surv., Bull. 340, pp. 348–363, 1907.

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Hintze, F. F., Jr., The Little Buffalo Basin oil and gas field, Wyo. State Geol. Surv., Bull. 11, pt. 1, 1915.

Lupton, C. T., Oil and gas near Basin, Bighorn County, Wyoming, U. S. Geol. Surv., Bull. 621L, 1916.

Ziegler, V., The Byron oil and gas field, Bighorn County, Wyoming, Wyo. State Geol. Surv., Bull. 14, 1917.

——, The Oregon Basin gas and oil field, Park County, Wyoming, Wyo. State Geol. Surv., Bull. 15, 1917.

PHYSIOGRAPHY AND DRAINAGE

The area covered by this report lies in the transitional region between the Shoshone Mountains on the west and south and the Bighorn Basin on the east. Its average elevation is about 6400 feet, or about 1400 feet higher than the average for the Bighorn Basin. The streams from the near-by mountains occupy comparatively narrow, flat bottomed valleys, flanked by well developed stream terraces. Cut terraces, covered with a thin veneer of fluviatile gravels, are among the most striking topographic features of the region, forming as they do long, flat topped ridges usually paralleling the rivers. Along Wood River there are two well developed terraces, the higher 600 feet and the lower 200 feet above the present stream valley. These slope gently to the north at about 90 feet to the mile, which is very nearly the same as the fall of the river, and are shown in plate 37.

The principal drainage of the region shown on the map is through

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the Greybull River and its tributaries, Sunshine Creek and Wood River. Gooseberry Creek, to the south, drains a small area east of the Wood River divide. Greybull River takes its source in the depression between the Carter and Shoshone Mountains and pursues a general northeasterly trend to its confluence with the Bighorn River some seven miles above the town of Basin. Wood River rises high on the northeastern flank of the Shoshone Mountains and flows in a northerly direction to its junction with the Greybull at the northern limit of the map. Below the mouth of Wood River the Greybull has a mean discharge of 300 to 400 second-feet. Gooseberry Creek takes its headwaters from the lower slopes of the Shoshone Mountains and flows easterly to meet the Bighorn River about ten miles south of Worland; within the limits of the map it is a small stream averaging ten feet in width and one in depth.

All the streams are at present actively engaged in cutting. The veneer of fluviatile deposits upon the present flood plain, as upon the elevated terraces, is comparatively thin, and at times of high water the bedrock is laid bare along large portions of the stream-beds. In Sect. 16, T. 47 N, Wood River is energetically attacking the steeply dipping, resistant sands of the Benton, and has established a steep declivity at this point in its course. Greybull River is now removing material from the coal horizon of Erskine's mine where the Mesaverde formation passes gradually under the stream in a gentle syncline. Gooseberry Creek flows on bedrock over a large part of its course. The divides between the various catchment basins are yet essentially unattacked; the stream valleys are on the whole narrow and steep-sided, though a vast amount of material has already been removed. These facts, coupled with the absence of extensive graded tracts in the stream courses, seem to indicate that the present geomorphic cycle is in an early stage of maturity. There is little or no adjustment of Sunshine or Rawhide Creeks to the structure of the Mesaverde beds; but the small perennial streams that drain the large area of Cody shale north of Gooseberry Creek may be considered as essentially subsequent. The major streams—Greybull River, Wood River, and Gooseberry Creek—are undoubtedly to be classed as superimposed; they are totally out of accord with the structures of the older rocks. The key to their history is to be found on Gooseberry Creek, where the Wasatch beds are still unremoved over considerable areas. Gooseberry Creek unquestionably originated as a consequent stream upon a Tertiary terrane. As erosion progressed the folded Cretaceous rocks were encountered below the Wasatch contact, but as the stream was

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Fig. A—Looking north along axis of Sunshine anticline. Mowry shale in center flanked by Frontier formation.

Fig. B—Wasatch formation, north side of Redtop Mountain.

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intrenched, cutting within the discordant beds continued without alteration of direction of the stream course. The history of the larger streams is undoubtedly more complex, but the main fact of their superposition from the Wasatch appears to be identical with what has happened more recently on Gooseberry Creek.

STRATIGRAPHY

Introduction.—The formations exposed at the surface within the area mapped are all sedimentary rocks. In age they range from the Lower Cretaceous to the Quaternary. Tertiary volcanics occur a few miles to the south of the southern limit of the area.

The succession of the formations, their age and characteristic features are given in the following table:

System or Series	Group	Formation	Thickness in feet	Character
Quaternary				Alluvium along stream courses
				Terrace gravels along Wood and Greybull Rivers, consisting of volcanic, limestone, and quartzite pebbles and boulders
Tertiary		Wasatch formation		Gray to red conglomerates and sandstones, white to bright red sandy clays, thin tuffaceous layers
Upper Cretaceous	Montana	Mesaverde formation	1000±	Tan, buff, and gray sandstones, buff sandy shales, carbonaceous shales and coal beds
		Cody shale	1800±	Dark gray and black shales with numerous calcareous and limonitic concretions, gray and buff sandy shales and thin sandstones
	Colorado	Frontier formation	583	White to brown sandstones and sandy shales; ratio of sandstone to shale 7:5
		Mowry shale	380	Hard blue black fissile shales and dark gray sandy shales with a few hard sandstone layers. Fish scales, fins, and teeth abundant
		Thermopolis shale	470	Rather soft dark shales, thin brown sandstones
Lower Cretaceous		Cloverly formation	305+	Dakota (?) sandstone member at top, 55 feet thick. Red, gray, and buff clays and sandy clays, gray to lilac limestone and gray sandstones

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CRETACEOUS SYSTEM

Cloverly Formation.—The Cloverly formation is exposed only in the center of the Gooseberry Creek fold where it has been cut across by Gooseberry Creek. The formation here consists of reddish clays, drab and buff sandy clays, thin buff clayey sandstones, a soft white to gray, cross bedded, medium grained sandstone, and gray to lilac limestone with thin lilac shale partings. At the top is a firmly cemented, massive, ripple marked, somewhat cross bedded, fine to medium grained, gray to brown colored sandstone that closely resembles the Dakota and may be its equivalent. Stratigraphically it occupies the position of the Dakota, being immediately below the dark Benton shales. This resistant sandstone stands out sharply from the soft shales both above and below it, and gives a crater-like form to the crest of the fold (pl. 35 and 36A), and forms an almost vertical wall on the east limb through which Gooseberry Creek has cut a narrow notch as shown in plate 36B.

The limestone is a dull gray to lilac gray, dense rock much veined with calcite. Small veins of opal up to one-sixteenth inch in width are occasionally seen. Under the microscope the limestone is seen to consist of very fine granular calcite, the individual grains averaging less than 0.01 mm. in diameter. This fine grained aggregate is occasionally pink to red in color, probably due to finely divided red iron oxide. Small grains of quartz up to 0.07 mm. are scattered through the rock. No organic remains were present in the slide examined.

SECTION OF THE CLOVERLY ON GOOSEBERRY CREEK

Thermopolis shale.	FEET
Dakota(?) sandstone, hard, massive and ripple marked	55
Reddish clays and buff sandy clays, thin sandstone layers	75
Dense gray to lilac limestone with thin partings of lilac shale	5
Red and buff clays and sandy clays	35
Soft white to gray, medium grained, cross bedded, rather well washed quartz sandstone, the upper four or five feet thin bedded and calcareous	35
Red, gray, and chocolate shales, buff sandy shales and thin sandstones, base not exposed	100
Total	305

The lower red shales, below the soft gray sandstone, may represent the Morrison formation. However, as the authors have no definite evidence as to this point, the lower shales are included in the Cloverly.

Thermopolis Shale.—The name Thermopolis shale was first given

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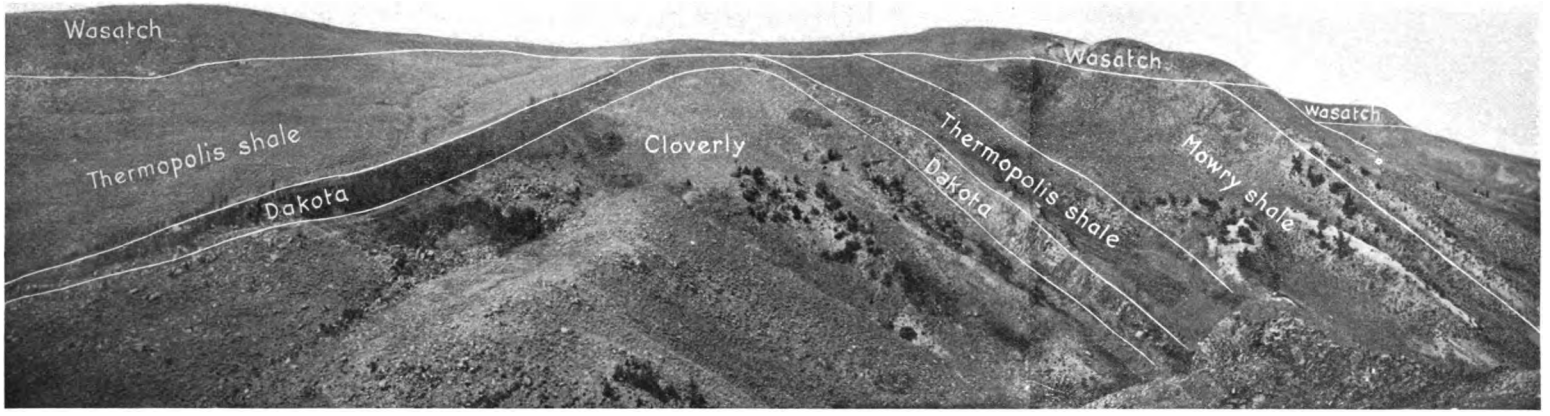

North end of Gooseberry Creek Anticline, showing the Wasatch formation lying unconformably over the Cretaceous.

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by Lupton[1] "to a mass of generally shaly rocks, limited below by the top of the upper sandstone bed of the Cloverly (Greybull Sand), and above, also conformably, by the base of the Mowry shale. It is named from the town of Thermopolis, in Hot Springs County, near which it is well exposed."

From the stratigraphic position the authors refer the dark shales lying above the top of the Cloverly (Dakota sandstone) and below the base of the Mowry in the area mapped to the Thermopolis shale. Here it is very similar to the beds of the type section. This formation is exposed only in the Gooseberry Creek anticline where it forms the small valleys flanking the hard Dakota sandstone. It conformably overlies the Dakota and consists at the base of dark, almost black, rather soft sandy shales with numerous thin rather calcareous brown sandstone lenses one-fourth inch to four or five inches in thickness. Near the base these sandstone layers are almost equal in amount to the shale, but higher up in the formation the black shales rapidly become predominant. Toward the top the black shales again become somewhat sandy and thin sandstones are present. No thick sandstone member was noted such as the Muddy sand[2] in the Basin region. The thickness of this formation, as measured on the east limb of the Gooseberry Creek fold, is 470 feet.

Mowry Shale.—Conformably overlying the black Thermopolis shales are the hard blue black fissile Mowry beds. This formation outcrops in both the Sunshine and Gooseberry Creek folds, its entire thickness being exposed only in the latter. These shales weather to a bluish or silver gray color and usually form low, well wooded hogbacks. Considering its wide distribution and persistent character, the authors agree with Lupton[3] in considering the Mowry as a distinct formation rather than as a member.

SECTION OF THE MOWRY SHALE ON THE EAST LIMB OF GOOSEBERRY CREEK ANTICLINE

	FEET
Frontier formation.	
7. Hard, dark, very sandy shales with thin sandstone layers	74
6. Coarse, rather hard sandstone	6
5. Hard, blue black to chocolate colored shales	33
4. Sandy shale and shaly sandstone	5
3. Dark shales, hard and fissile	67
2. Hard brownish gray sandstone	5
1. Hard, blue black, fissile siliceous shale	190
Thermopolis shale.	
Total	380

[1] Lupton, C. T., Oil and gas near Basin, Bighorn County, Wyoming, *loc. cit.*, p. 168.

[2] *Loc. cit.*, pp. 167, 168.

[3] *Loc. cit.*, p. 169.

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Fish scales are very numerous in the Mowry shales and fins are frequently found, especially in the sandstone members. Fish teeth are occasionally found, but the bony parts are rarely if ever encountered.

Fish scales, teeth, and fins are very abundant in nos. 1, 2, and 3, scales being especially numerous in no. 1. Scales are frequently found in the upper members, but they are not so abundant as in the lower. They are rather rare in no. 7.

Several thin sections of Mowry shale from various parts of Wyoming were examined. The following is a description of a specimen from the southwest limb of the Emigrant Gap anticline, about 10 miles west-southwest of Casper. In the hand specimen this is a very dark gray, hard platy shale which splits readily into plates one-eighth to one-half inch in thickness. When broken across the bedding it has a somewhat conchoidal fracture. It weathers to a silvery gray color. Fish scales up to three-fourths inch in diameter are common, and fins up to four inches in length are occasionally found. In thin section the color is brown, due to organic matter. In extremely thin sections the color is very pale brown to brownish gray. Under crossed nicols the material of the shale is shown to be largely isotropic, with a few very minute fragments of quartz and feldspar. The shale cannot be resolved into its constituents even with the highest power.

A hard dark gray to black siliceous, somewhat sandy shale from the Mowry of the Sunshine anticline shows very angular fragments of plagioclase and quartz up to 0.20 mm. in size. These fragments are very irregularly distributed, being rather closely spaced in some areas and almost entirely lacking in others. The feldspar, which is chiefly albite and albite-oligoclase, is equal in amount to, or slightly predominates over the quartz. A sandstone from the Mowry of the same locality shows angular fragments of quartz, plagioclase, and occasionally a fine grained quartzite fragment embedded in a brown calcareous matrix. No remains of diatoms were seen in any of the slides examined and in only one slide were radiolaria found. These were in a chert from the Mowry of Oil Mountain anticline, about 25 miles west of Casper. In the hand specimen this chert is dark blue gray to black on the fresh surface, weathering to a dull white or light gray, and breaks with a conchoidal fracture. The rock is dotted with small dull white spots ranging up to one millimeter in diameter. There are usually about forty to forty-five of these spots to the square centimeter of surface. These spots become larger and more numerous toward the weathered surface of the rock, and finally this surface is covered with a dull white to gray film. In thin section

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and without crossed nicols the spots are a dark gray and stand out sharply from the mass of the rock, which is pale brown in color, and which is made up of cryptocrystalline silica. The spots are usually somewhat elliptical and average 0.66 by 0.45 mm. With crossed nicols the spots are indistinguishable from the mass of the rock, the whole being largely isotropic. The spots are somewhat more cloudy than the remainder of the rock, but otherwise they are quite similar to it. The slight banding of the chert passes through the spots without any change in character. These spots seem to be made up of opal or of amorphous silica and it is possible that they represent centers of weathering. Two small radiolarian tests were seen in this slide. They were 0.12 mm. in diameter.

Frontier Formation.—The Frontier formation consists of about 600 feet of sandstone and shale, the ratio of sandstone to shale being about seven to five. The degree of induration of the sandstones is variable, individual beds changing rather rapidly from hard and well cemented to soft and crumbling layers. The cement is generally calcareous. The thickness of individual beds is not constant. The lowest sandstone, for example, is 40 feet thick at the northern end of the Sunshine anticline and more than 60 feet thick on the east limb of the Gooseberry Creek fold. In general the sandstones are white to buff in color, cross bedded, fine to coarse grained, and with only a small percentage of ferro-magnesian constituents. Carbonized wood fragments are present in some of the layers of the upper sandstone member. This formation outcrops along the flanks of the Sunshine and Gooseberry Creek anticlines and forms the crest of the small minor fold lying between these anticlines. In general the sandstone members of the Frontier formation form low, rather well wooded ridges, separated by shallow depressions which are occupied by the shales.

The following section is given by Hintze:[4]

SECTION OF UPPER PART OF BENTON FORMATION, ON WOOD RIVER

Cody shale.	FEET
Light brown sandstone, upper layers conglomeratic	62
Sandy shale and dark adobe shale	167
Light gray massive sandstone	64
Light brown and gray, thick bedded sandstone	108
Hard, white massive sandstone	54
Light brown sandy shale, thin bedded	83
Massive hard gray sandstone	45
Total	583

[4] Hintze, F. F., Jr., The Little Buffalo Basin oil and gas field, *loc. cit.*, p. 75, 1915.

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These are the oil-bearing sandstones of the productive Grass Creek field, which lies about sixteen miles to the west-southwest.

Cody Shale.[5]—The Cody shale in this region consists of soft blue black shales, dark sandy shales, and thin brown and gray sandstones. In the lower part the soft black shales carrying numerous limonitic and iron-rich calcareous concretions predominate. Toward the top the shales become more sandy and slightly lighter in color. Thin, more or less lenticular sandstones occur throughout the formation. No attempt was made to separate the formation into the Basin and Pierre shales. The thickness as calculated from dip readings and width of outcrop is 1800 feet.

This formation is exposed on the flanks of both the Sunshine and Gooseberry Creek anticlines, and where unprotected by the Wasatch formation or the Quaternary gravel it occupies valleys characterized by bad-land topography.

Mesaverde Formation.—The Mesaverde formation conformably overlies the Cody shale and within the limits of the area mapped consists of about 900 feet of tan and buff sandstones, buff sandy shales, gray sandstones, carbonaceous shales and coal beds. The coal beds are associated with a thick massive white to gray sandstone not far above the base of the formation. Carbonized wood fragments and plant remains are numerous. No detailed study of this formation was made in the field.

The Mesaverde formation is exposed on the east, west, and north sides of the area mapped. Its outcrop is usually marked by steep cliffs several hundred feet high where it rises above the soft Cody shale. It is locally known as the "rim-rock" and is an effective barrier to transportation except where cut through by streams.

TERTIARY SYSTEM

Wasatch Formation.—The Wasatch formation unconformably overlies all of the older formations exposed in the area. It consists of conglomerates, conglomeratic sandstones, sandstones, tuffs, and clays of continental origin. The lower part is almost wholly composed of conglomerates and rather hard massive sandstones with thin layers of white tuff often containing small rather angular pebbles. The pebbles of the conglomerates and the grains of the sand are subangular to fairly well rounded. The upper part is made up chiefly of white to

[5] This formation includes the Basin shale and Pierre shale of Hintze's classification. *Loc. cit.*, pp. 76, 77.

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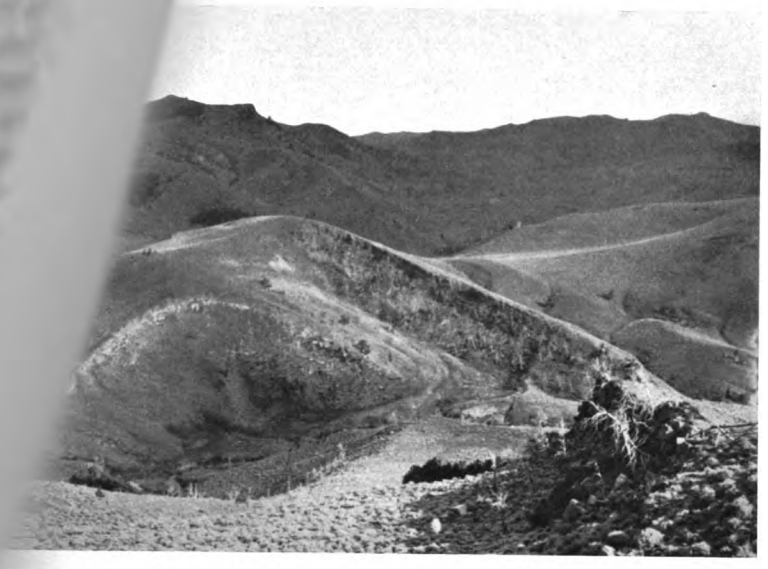

A—South end of Gooseberry Creek anticline, looking south.

Fig. B—Dakota sandstone on east limb of Gooseberry Creek anticline. Looking southwest up Gooseberry Creek.

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bright red clays, the red clays predominating. This formation was not studied in detail. It is limited to the southern part of the area and occupies only the highest points and ridges.

The tuffaceous beds form only a small part of the formation, usually being thin intercalations in the sandstone. Some of the beds are as much as 8 feet thick. In the hand specimen they are white to light gray in color, rather hard and well cemented and usually pebbly, with small subangular pebbles up to one-fourth inch in diameter. These pebbles are usually volcanic rock.

In this area at least the Wasatch was laid down on a surface of moderately high relief. Section C–D through the Gooseberry Creek anticline shows the Wasatch lying unconformably on the older formations (pl. 34B and 35).

QUATERNARY SYSTEM

Terrace Gravels.—The Quaternary was marked by active erosion in the high mountainous regions to the south and west, and by the deposition of rather extensive sheets of terrace gravels far out into the basin. There are at least two distinct periods of gravel deposition. The earlier is represented in this area by coarse gravels capping the higher terraces, remnants of which are found on both sides of Wood and Greybull Rivers. Along Wood River the elevation of these higher terraces is about 7000 feet. They slope gently to the north at about 90 feet to the mile. Subsequent erosion has removed all but relatively small areas of these gravels. The terraces produced during the second period of gravel deposition are about 400 feet lower than the earlier and 200 to 250 feet above the present stream valleys. These later terraces are extensively developed along Wood and Greybull Rivers. No terraces, except the present flood plain, were seen along Gooseberry Creek.

The deposits of both periods are essentially the same. They consist of silt, sand, and fine to coarse gravel. Boulders up to 8 or 10 inches in diameter are common. The boulders are chiefly porphyritic volcanic rocks derived from the near-by mountains. Boulders of quartzite and limestone are also common. All of the pebbles and boulders are well rounded.

Alluvium.—Alluvium covers the flat bottomed, rather narrow valleys of Wood and Greybull Rivers, Gooseberry Creek and their tributaries. It consists of sand, silt and some coarse gravels and varies in thickness from 0 to 20 feet.

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STRUCTURE

The dominant structural feature of the area is a rather long anticline trending somewhat west of north by east of south, roughly paralleling the front of the Shoshone Mountains. The long strip of Mesaverde shown along the eastern side of the map represents the eastern limb of this fold. The small anticlines mapped are minor folds along the axis of this larger anticline. This larger fold is one of several along the southwestern border of the Bighorn Basin. These folds become broader and flatter and progressively younger rocks are exposed on their crests as the center of the basin is approached.

As shown by the sketch map (pl. 38), three folds whose axes are arranged more or less *en echelon* form the crest of the larger anticline. The most northerly and largest anticline will be referred to as the Sunshine anticline and the most southerly as the Gooseberry Creek anticline.

Sunshine Anticline.—This fold is about 4½ or 5 miles in length and extends from Redtop Mountain to north of Wood River. In the southern part of the fold the axis trends a few degrees east of north. Just north of the center the axis makes a rather sharp turn to the northwest and then trends N15°W. The southern part is symmetrical, the dips being 31°E on the east and 33°W on the west limb. Toward the northern part the dip of the east limb decreases to 20°, while that on the west increases until it reaches a maximum of 51°. The anticline plunges at both ends, the dip to the south being 6°. On the north the angle at which the anticline plunges could not be measured owing to the capping of terrace gravels. The fold dies out to the south, no trace of it being found south of the Tertiary mantle forming Redtop Mountain.

The Mowry shale is the lowest formation exposed in the Sunshine anticline. This formation with its hard sandstone members forms the ridge which follows the axis of the fold in the southern and central parts (pl. 34A). Flanking this central ridge are minor ridges separated by small depressions. Outcropping along these flanking ridges are the sandstone members of the Frontier formation, the depressions being occupied by the Frontier shales. Beyond these low ridges along the eastern side of the fold is a broad depression cut from the Cody shale. North and west of Wood River the anticline finds no expression in the topography on account of the flat terraces cut in earlier stages in the history of Wood River. The Frontier formation closes around

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Junction of Wood and Greybull rivers, showing well developed terraces.

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both ends of the fold. The southern end of the fold is covered by the Wasatch formation which unconformably overlies the older formations and on the north much of the anticline is covered by terrace gravels and alluvium.

South and somewhat west of the Sunshine anticline is a sharp minor anticline whose axis trends about N35°W. This is separated from the Sunshine anticline by a relatively shallow syncline in which the lower part of the Cody shale is exposed. This syncline is largely covered by the Wasatch, but in all probability it dies out rapidly in the Cody shale both to the northwest and the southeast. The Frontier is the lowest formation exposed at the surface in this fold. Here the uppermost sandstone member of the Frontier is a white to gray, brown weathering sandstone with some very well indurated layers. Casts of *Inoceramus* and other marine lamellibranchia are rather numerous. The east limb of this anticline dips 67°NE and the west limb 57°SW. On the north the Frontier closes just as it disappears under the overlying Wasatch formation.

Gooseberry Creek Anticline.—Southwest of the minor fold described above, and separated from it by a sharp narrow syncline in which the lower part of the Cody shale is exposed is the Gooseberry Creek anticline. Gooseberry Creek cuts transversely across the center of this fold, exposing the Cloverly formation in the center. On its flanks are exposed the Thermopolis shale, Mowry shale, Frontier formation, and Cody shale. This is a much sharper fold than the Sunshine anticline, but it dies out rapidly to the north. Its southern limit is not known, as not far south of the area mapped it is covered by the Wasatch formation. However, the Dakota sandstone, which closes at both ends of the fold, plunges rather steeply both to the north and south, indicating that this anticline, in spite of its greater width, is shorter than the Sunshine anticline.

This comparatively short fold is asymmetric, being much steeper on the east than on the west, being in this respect the reverse of the northern part of the Sunshine anticline. The east limb dips 73°E and the west limb 22°W. The trend of the axis is N 25°W, S 25°E.

In the Mowry shales on the east limb a small amount of overturning and even slight overthrusting of 15 or 20 feet has taken place. This overthrusting is confined to the Mowry shale, the massive Frontier sandstones being unbroken.

The larger folds along the southwest side of the Bighorn Basin trend northwest-southeast and must have been produced by compres-

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sional forces acting at right angles to this general trend. The small folds mapped may be due to minor forces or reactions which acted in a nearly north-south direction, producing minor flexures along the axis of some of these larger folds. This might account for the arrangement of the axes *en echelon* and for the steeper dips on the west limb of the more northerly anticline and on the eastern limb of the more southerly anticline.

GEOLOGIC HISTORY

The variegated shales and cross bedded sandstones of the Cloverly formation represent shallow water conditions, and the plant remains found in it in other districts indicate that it is of fresh water origin. The Dakota is a shallow water deposit and represents the encroachment of the Upper Cretaceous sea. The Thermopolis shales and thin sandstones represent progressive subsidence and deposition in only moderately deep water. The hard siliceous Mowry shale with its numerous fish scales indicates a rather sudden influx of marine vertebrates and the precipitation of silica. Sufficient data are not at hand to determine what climatic factors brought about this change. The sandstones and sandy shales of the Frontier formation indicate a return to rather shallow marine conditions; the formation marks the most important break in shale deposition between the top of the Dakota and the base of the Mesaverde, and may represent a period in which subsidence did not keep pace with deposition. The dark shales, sandy shales and the lenticular sandstones of the Cody formation represent moderately deep water in which subsidence and deposition were almost balanced. Following the deposition of the Cody shale there was a gradual withdrawal of the sea and the sandstones, sandy shales, carbonaceous shales, and coal deposits of the Mesaverde were laid down in brackish water along a low coast. This was followed by the deposition of fresh water beds which are not represented in this area. At the close of the Cretaceous extensive uplift and folding took place and the present structural features were formed. A period of erosion followed and the folds were truncated.

Tertiary Period.—In the early Tertiary the products of the erosion of the high mountains to the west were deposited along their flanks and well out into the Bighorn Basin, forming the Wasatch formation, which is a continental deposit laid down on a surface of moderate relief. These beds rest with marked unconformity on the older for-

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mations. The Wasatch formation has been only slightly warped and tilted.

Quaternary Period.—In Quaternary time streams from the high mountains to the south and west developed broad flood plains and deposited rather thin, but extensive, sheets of silt, sand, and fine to coarse gravel. Uplift, without tilting or folding, or possibly the removal of a barrier far down stream, caused active erosion to begin and the streams to cut down to a new level, removing all but scattered remnants of their old flood plains. New flood plains were formed and a thin sheet of silt, sand, and gravel again deposited. Another period of renewed erosion caused the streams to erode to a still lower level, forming the present stream valleys.

SUMMARY

South and east of Sunshine, Wyoming, are three rather small anticlines, involving the Cloverly formation and the Colorado and Montana groups, whose axes are arranged *en echelon,* forming the crest of a larger fold. The axis of the most northerly fold, known as the Sunshine anticline, follows a somewhat sinuous course in a general north-south direction, while the axis of the most southerly fold, known as the Gooseberry Creek anticline, trends N 25° W. The northern part of the Sunshine anticline is asymmetric with the steeper dip on the west, while in the asymmetric Gooseberry Creek anticline the steeper dip is on the east. The Mowry shale is exposed along the axis of the Sunshine anticline and the Cloverly formation along the axis of the Gooseberry Creek anticline.

The Wasatch formation (early Tertiary) overlies the older formations with marked unconformity. It has been only slightly warped and tilted.

Cut terraces covered with Quaternary gravels have been developed along the streams.

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THE PLEISTOCENE FAUNA OF HAWVER CAVE

BY
CHESTER STOCK

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INTRODUCTION

The limestone caves of California have been the object of much fruitful investigation on the part of students of anthropology and palaeontology concerned especially with the search for evidence bearing on the problem of early man in America Although up to the present time no indisputable evidences of Pleistocene man have been found in these caves, there remain for consideration in the anthropological sense many important problems relating to the origin, evolution, migrations and habits of the mammals which constituted a part of the environment in which Pleistocene man must have moved if present in this region.

In purely palaeontologic studies the cave faunas are of unusual importance, representing as they do an aspect or a zone of mammalian life not preserved in the more common lacustrine, fluviatile and alluvial accumulations. The recognition of contemporaneity of distinct aspects of faunas, each occupying its own particular type of environment in an extensive geographic province, is of great value in such studies. Thus the importance of mammals from deposits such as Potter Creek and Samwel Caves in Shasta County, inhabiting, as they apparently did, a region physiographically distinct from the adjacent Great Valley of California, can hardly be overestimated.

The present study of the mammalian fauna from Hawver Cave is in a manner supplementary to the exhaustive investigation of Potter Creek Cave by W. J. Sinclair and the researches of E. L. Furlong on Samwel Cave. Although the material from Hawver Cave is fragmentary and not so abundant as that from the Shasta deposits, it is unique in the possession of certain forms heretofore unrecorded from Pleistocene caverns of the state.

It is great pleasure to acknowledge indebtedness to those connected with the furtherance of this work. The present research owes its origin to the late Dr. J. C. Hawver of Auburn, California, who first brought the cave and its significant fossil contents to the attention of the University of California. Dr. Hawver followed the scientific work with a sympathetic interest and his assiduous prosecution of collecting work made possible the assembling of a good representation of the Pleistocene vertebrates from the cave. This collection was very kindly presented by Dr. Hawver to the Department of Palaeontology, University of California, and forms the basis of the following study.

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The investigation of the mammalian remains has been made under the supervision of Professor John C. Merriam, to whom the writer is obligated for much counsel and advice. In comparing the Pleistocene remains with Recent forms, the collections of mammals in the California Museum of Vertebrate Zoology were freely drawn upon, and the writer wishes to express thanks to Director Joseph Grinnell and other members of the staff for many courtesies extended during the progress of the work.

During early stages of the research, the writer visited Hawver Cave and explored the cavern under the guidance of the late Dr. Hawver. While the work was in course of completion, a second examination of the cave was made. During the last visit the writer was very cordially received and much valuable aid was rendered him by the Pacific Portland Cement Company. The limestone quarry now being operated by this company is situated along the Middle Fork of the American River not far from Hawver Cave. Grateful acknowledgment for much kindness is given to M. J. Johnsson, superintendent of the quarry.

All the text-figures of this paper have been prepared by Mrs. Louise Nash.

HISTORY OF PREVIOUS INVESTIGATIONS

Originally discovered in the early eighties when the region was actively quarried for limestone, Hawver Cave was subsequently brought to the attention of the University of California by the late Dr. J. C. Hawver of Auburn, California. In 1907, E. L. Furlong[1] reported on a reconnaissance of the cave, naming the deposit in recognition of Dr. Hawver's energetic exploration of the cavern and removal of the fossil remains. Furlong's studies were curtailed by the rise of the water level in the cave, which prevented the removal of much material. The preliminary report of Furlong includes, therefore, only a provisional list of the mammals found.

As a result of subsequent excavation by Dr. Hawver much additional material was removed. This is now in the palaeontological collections of the University of California. In 1909, Professor John C. Merriam[2] discussed briefly the occurrence of human remains in Hawver Cave. Later N. C. Nelson, then connected with the Anthro-

[1] Furlong, E. L., Reconnaissance of a recently discovered Quaternary cave deposit near Auburn, California, Science, n.s., vol. 25, pp. 392–394, 1907.

[2] Merriam, J. C., Note on the occurrence of human remains in California caves, Science, n.s., vol. 30, pp. 531–532, 1909.

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pological department, University of California, commenced detailed mapping of the various chambers of the cave.

The bird remains obtained in the course of excavation of Hawver Cave have been studied by Dr. L. H. Miller,[3] and the report on these forms included also a short discussion of the occurrence of the vertebrate remains.

LOCATION OF HAWVER CAVE

Hawver Cave is located in Eldorado County five miles almost due east of Auburn, and is approximately 150 miles to the southeast of Potter Creek Cave and Samwel Cave in Shasta County. It is situated to the south of the Middle Fork of the American River at an elevation of 1300 feet or about 700 feet above the present bed of that stream. The county road which extends from Auburn to Cool and thence to Placerville passes immediately to the southwest of the entrance to the cave.

As shown by the areal geology mapped in the Sacramento folio,[4] a narrow strip or lens of limestone, lying within an area of amphibolitic schist, extends in a northerly direction from the vicinity of Cool to the Middle Fork of the American River and slightly beyond the north bank of that stream. At the present time this limestone, as exposed on the south bank, is being extensively quarried by the Pacific Portland Cement Company. Indications of earlier operations are still to be seen in the presence of deserted lime-kilns situated close to Hawver Cave.

RELATION OF CAVE TO TOPOGRAPHY

A noticeable physiographic feature of the Sierran region in the vicinity of Hawver Cave to-day is the remarkably even sky-line, indicative of a former physiographic cycle which plainly marks the 1500-foot elevation. The present bed of the Middle Fork lies approximately 900 feet below this level. It is generally assumed that the major cutting of the cañons, characteristic of the principal streams of the Sierra Nevada, such as the American River, was accomplished after the Sierran uplift which produced the eastern fault-scarp, and occurred presumably during early Pleistocene time. Whether or not the his-

[3] Miller, L. H., Contributions to avian palaeontology from the Pacific coast of North America. Univ. Calif. Publ., Bull. Dept. Geol., vol. 7, pp. 73–75, 1912.

[4] U. S. Geologic Atlas, Sacramento Folio, no. 5, 1894.

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tory of cañon-cutting of these streams involves certain quiescent periods of such length as to allow extensive terraces to be developed, is a matter which can not be adequately discussed as a result of study of the American River directly east of Auburn and of its course in the vicinity of Hawver Cave. Information relating to this problem can perhaps be furnished most satisfactorily by an extensive investigation of streams composing the western watershed of the Sierra Nevada. It has therefore not been found possible at Hawver Cave to associate the Pleistocene fauna from the cavern with the formation of terraces along the adjacent river, as has been done for Potter Creek Cave on the McCloud River in Shasta County.

The present course of the Middle Fork is directly athwart the lens of limestone in which Hawver Cave is situated, and there is no reason for believing that the direction of flow of the stream was materially different during Pleistocene time. Apparently the American River must have cut below the old surface, at least to a depth now indicated by the floor of the cave, before extensive leaching of the limestone could have been accomplished. The latter process probably aided the weathering of the limestone, and, due perhaps to a more favorable surface drainage, its results may have been greater in the past. At the present time the limestone is weathered in places on the surface, forming crags and numerous fissures. That such open fissures or chasms were developed in the limestone during the Pleistocene, and that large animals either fell or were dragged into them, seems to be indicated by the association of parts of skeletons belonging to individuals of the ground-sloth *Nothrotherium*.

Finally, either the chambers of the cavern were entirely filled with osseous material and debris or, as seems not at all unlikely, their entrances from above were temporarily closed. The present entrance to the cave is approximately on a level with a locally developed flat, the formation of which may have been connected with the sealing of the Pleistocene deposits in the cave. No typical terrace accumulations were observed on the flat and it seems to have been formed as a topographic feature incidental to the erosion accomplished by the Middle Fork and by small tributaries of that branch of the American River. This topographic development may account for the pools of water present in all the principal chambers of Hawver Cave even during the summer months. No noticeable movement was observed in these pools and they probably serve as temporary reservoirs for water which is either slowly seeping to lower levels in the limestone or appearing

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on the surface as springs. This water is still at work leaching certain areas of the limestone as well as closing cavities by the deposition of carbonate of lime and by the formation of stalactitic growths. Its work now, however, can only be regarded as a minor process, considered in the light of what it has accomplished in the past; and this appears to be principally due to the location of the cave, situated high and dry, as it were, on a spur whose surface supply of water is speedily carried away through the adjacent small gullies.

PRESERVATION OF VERTEBRATE REMAINS

The matrix from which many of the bones were obtained, is a cave-breccia. A typical specimen of the deposit consists of a mixture of numerous irregular fragments of limestone, broken pieces of stalactite and bone fragments together with a reddish-brown dirt derived from the surface soil. The whole is thoroughly cemented with carbonate of lime. A number of the bones were secured from the cave-breccia with some difficulty, while others were imbedded in a less indurated matrix and were easily removed.

The vertebrate material is for the most part fragmentary. There are no complete skulls or skeletons. Occasionally a few parts of a skeleton were directly associated in the same block of breccia and evidently belonged to the same individual. Some of the larger remains, such as bones of the ground-sloth, had been subjected to much wear before final entombment, so that recognition of parts is often impossible. All of the larger bones are thoroughly impregnated with carbonate of lime.

Mixture of apparently Recent mammalian material with Pleistocene fossils has in several instances been noted by the writer. These occurrences are, however, few, and so far as observed they seem to be restricted to the smaller forms. The appearance of the material in question offers in each case sufficient ground for suspicion as to its age.

OCCURRENCE OF HUMAN REMAINS

The occurrence of remains of man in Hawver Cave was investigated by Professor Merriam and by members of the Anthropological department of the University of California. In a short note Professor Merriam[5] makes the following statement concerning the human finds:

[5] Merriam, J. C., Note on the occurrence of human remains in California caves, Science, n. s., vol. 30, pp. 531–532, 1909.

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... In March, 1908, while attempting to open what Dr. Hawver supposed to be an ancient passageway into the lower cave, a number of human bones were found at a depth of twenty feet below the surface, under a mass of cave earth, fallen rocks and soil, over twelve feet in thickness. The remains lay at the lower end of a passageway which has evidently been closed for a long period. In this case, as in that of Mercer's Cave, remains of extinct animals undoubtedly of Quaternary age were found near the human bones, but the degree of alteration of the unquestionably Quaternary bones differs from that in the human skeletons. Some of the human bones were embedded in a cemented breccia consisting largely of angular fragments of limestone. So far as examined the bones seem to have lost most of their organic matter. A fairly preserved skull in the collection does not differ strikingly from the crania of the modern California Indians, although no comparative study has yet been made by a specially trained craniologist.

It is not possible in the case of the Hawver Cave relics to prove Quaternary age for the human bones. As in the other instances mentioned, the inference is, however, that the date of their entombment preceded the present day by centuries, if not by milleniums.

MAMMALIAN FAUNA

Of the numerous cave deposits known from California, only three, namely Potter Creek Cave and Samwel Cave in Shasta County and Hawver Cave in Eldorado County, have yielded Pleistocene mammalian remains in sufficient quantity and completeness to allow of broader faunal studies. The deposits may be ranked in the order named according to actual amount of material secured. Mention could be made of other fissure accumulations from which Pleistocene mammals have been recovered. Mercer's Cave near the town of Murphys, Calaveras County, has yielded mammalian remains, but the material offers only limited information concerning the fauna which lived in the vicinity of that cave during Pleistocene time.

From Hawver Cave twenty-four species of mammals are known as contrasted with thirty-four species from Samwel Cave and forty-six species from Potter Creek Cave. It is not improbable that more intensive study of the fauna from Samwel Cave will reveal a number of additional forms from that deposit. Results of such future studies will be expressed in the establishment of other species and subspecies, but it is less likely that extinct genera will be added.

Among the twenty-four species of mammals known from Hawver Cave, the presence of such typical Pleistocene forms as *Smilodon(?)*, *Nothrotherium, Mylodon* and *Euceratherium* indicates the Pleistocene age of the deposit. Aside from this, however, the fact that twelve, or half the number of forms present, are extinct, conclusively proves Pleistocene age for the fauna. The percentage of extinct species from

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Hawver Cave is relatively greater than the percentage of extinct species from either Samwel Cave or Potter Creek Cave. Furlong believes that the Samwel Cave fauna represents a somewhat later stage of the Pleistocene than does the fauna from Potter Creek Cave. Judging only from a comparison of percentages, it would appear that the Hawver Cave fauna is older than that from Potter Creek Cave. As will be indicated below, this determination of the relative age of Hawver Cave is, however, not compatible with that based upon other lines of evidence.

The mammalian faunas from the three principal California caves may be conveniently contrasted in the following lists. An asterisk or a dagger denotes an extinct subspecies or species. A double dagger indicates that the genus is extinct.

HAWVER CAVE

Scapanus, possibly n. sp.
Ursus, sp.
†Canis, near dirus Leidy
Canis ochropus Eschscholtz
Procyon psora Gray
Mephitis occidentalis Baird
‡Smilodon(?), sp.
†Felis hawveri, n. sp.
†Felis, probably n. sp.
Peromyscus boylei (Baird)
Neotoma fuscipes Baird
Microtus, sp.
Thomomys, sp.
?Aplodontia, sp.
Citellus beecheyi (Richardson)
†Lepus, probably n. sp.
‡Mylodon harlani Owen
‡Megalonyx(?), sp.
‡Nothrotherium shastense hawveri, n. subsp.
Odocoileus, sp.
‡Euceratherium collinum (?) Sinclair and Furlong
†Bison, sp.
†Equus, sp.
‡Mammut (tooth fragment)

POTTER CREEK CAVE[1]

Scapanus latimanus (Bachman)
Antrozous pallidus pacificus Merriam, C. H.
‡Arctotherium simum Cope
†Ursus, n. sp.
†Canis dirus Leidy
Vulpes cascadensis Merriam, C. H.
Urocyon cinereoargenteus townsendi Merriam, C. H.
Bassariscus astutus raptor (Baird)
Mustela arizonensis (Mearns)
†Spilogale, n. sp.
Mephitis occidentalis Baird
Taxidea, n. sp.(?)
†Felis, probably n. sp.
†Felis, n. sp.
Lynx fasciatus Rafinesque
Lynx fasciatus, n. subsp.(?)
Neotoma cinerea occidentalis Baird
Microtus californicus (Peale)
†Thomomys microdon Sinclair
Thomomys leucodon Merriam, C. H.
*Aplodontia californica fossilis Sinclair
Marmota flaviventer (Audubon and Bachman)
Citellus beecheyi douglasi (Richardson)
Eutamias, sp.
Callospermophilus chrysodeirus (Merriam, C. H.)
Sciurus douglasi albolimbatus Allen
Sciuropterus alpinus klamathensis Merriam, C. H.
Sylvilagus auduboni (Baird)
‡Nothrotherium shastense Sinclair
‡Megalonyx wheatleyi(?) Cope
‡Megalonyx jeffersoni(?) (Desmarest)
‡Megalonyx, n. sp.
‡Megalonyx, sp.
‡Camelid

[1] Revised list.

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†Bison, sp.
Odocoileus, sp. a
Odocoileus, sp. b
‡Euceratherium collinum Sinclair and Furlong
Oreamnos americanus (Ord)
‡Platygonus(?), sp.
†Equus occidentalis Leidy
†Equus pacificus Leidy
‡Mammut americanum (Kerr)
†Elephas primigenius Blumenbach

SAMWEL CAVE[2]

Ursus americanus Pallas
†Ursus, n. sp.
Ursus, sp.
Vulpes, sp.
Urocyon cinereoargenteus townsendi Merriam, C. H.
Procyon, near lotor (Linnaeus)
Mustela arizonensis (Mearns)
Mustela, sp.
Mephitis occidentalis Baird
†Felis, probably n. sp.
Peromyscus maniculatus gambeli (Baird)
Neotoma cinerea occidentalis Baird
Microtus californicus (Peale)
†Thomomys microdon Sinclair
Thomomys leucodon Merriam, C. H.
Erethizon epixanthum Brandt
*Aplodontia californica fossilis Sinclair
Citellus beecheyi douglasi (Richardson)
Callospermophilus chrysodeirus (Merriam, C. H.)
*Sciurus griseus fossilis Kellogg
Sciurus douglasi albolimbatus Allen
Sciuropterus alpinus klamathensis Merriam, C. H.
Castor subauratus Taylor
Lepus washingtoni klamathensis Merriam, C. H.
Sylvilagus auduboni (Baird)
‡Nothrotherium shastense Sinclair
‡Nothrotherium, sp.
‡Megalonyx, sp.
Odocoileus, sp. a
Odocoileus, sp. b
‡Euceratherium collinum Sinclair and Furlong
‡Preptoceras sinclairi Furlong
Oreamnos, sp.
†Equus occidentalis Leidy
†Elephas, sp.

COMPARISON OF CALIFORNIA CAVE FAUNAS

Examining the faunas from the three caves as given in the foregoing lists we note the presence of ten distinct, or tentatively determined, genera which are extinct. These are distributed in each of the three deposits, as indicated in the following table:

Extinct Genus	Potter Creek Cave	Hawver Cave	Samwel Cave
Arctotherium	×	....	....
Smilodon(?)	....	×	....
Nothrotherium	×	×	×
Megalonyx	×	×(?)	×
Mylodon	....	×	....
Camelid	×	....	....
Euceratherium	×	×(?)	×
Preptoceras	....	....	×
Platygonus(?)	×	....	....
Mammut	×	×	....

As is shown in the above table, Potter Creek Cave possesses the greatest number of extinct genera, namely seven. Hawver Cave

[2] Partially revised list. Revision of rodents according to Louise Kellogg, Pleistocene rodents of California, Univ. Calif. Publ., Bull. Dept. Geol., vol. 7, pp. 151–168, 1912.

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follows next with six genera, while four extinct genera are known from Samwel Cave. Of the total number of extinct genera, three are common to the three caves. These are *Nothrotherium, Megalonyx* and *Euceratherium.* It should be noted here that the latter are types not usually associated with a typical plains fauna of the Pleistocene.

In the absence of arctotheres, camels and peccaries, the Hawver Cave fauna is more like that of Samwel Cave than like that of Potter Creek Cave, while in the absence of *Preptoceras* and the presence of a mastodon, it resembles more the fauna from the latter deposit. In this list we note also the presence of two forms, the ground-sloth *Mylodon* and a sabre-tooth tiger, which are new to the cave deposits of California.

Other comparisons of faunas from the Pleistocene caves should also be reported. The true bears probably occur at Hawver Cave, and are known from Potter Creek Cave and Samwel Cave. An extinct species of puma, related to the Recent *Felis oregonensis hippolestes,* occurs in all three deposits. The large, dire wolf, known by such abundant material at Rancho La Brea, is present in Potter Creek Cave, but absent from Samwel Cave. A large canid from Hawver Cave differs in certain respects from *Canis pambasileus* and approaches *C. dirus.* In other characters this form differs somewhat from the latter species. Remains of the California coon, *Procyon psora,* and of the skunk, *Mephitis occidentalis,* occur in Hawver Cave, but the nature of preservation of the material on which these determinations are based, casts suspicion on its Pleistocene age. Aplodont rodents have been reported from the Hawver Cave deposit by Furlong, but the material is not now available for a comparative study. An extinct subspecies, *Aplodontia californica fossilis* Sinclair, is known from Potter Creek Cave and from Samwel Cave.

The mountain goat, *Oreamnos,* does not occur at Hawver Cave in Eldorado County, but is known from Potter Creek Cave and from Samwel Cave in Shasta County. Deer are known from all three deposits, while bison are present in Hawver Cave and in Potter Creek Cave. Another ungulate characteristic of the three deposits is *Equus. Elephas* is absent from Hawver Cave, but is known from the other two caverns.

One may naturally enquire whether the differences between the faunas from Hawver Cave, Potter Creek Cave and Samwel Cave are due to actual differences in age of these deposits, or are merely expressions of local variation of an essentially unified fauna. Per-

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haps the distinctions noted between the faunas of Hawver Cave and those of the Shasta caves may be attributed in part to a difference in age and in part to the geographic separation of these deposits. It would appear that the latter factor was less potent in causing the differences between the faunas from Potter Creek Cave and Samwel Cave.

It has already been remarked that, judging from the relative number of extinct species in each of the three cave faunas, Hawver Cave would certainly appear to contain the oldest assemblage. On the basis of number of extinct genera present, however, the Hawver Cave fauna must be considered as somewhat older than the Samwel Cave fauna and slightly, if at all, younger than the Potter Creek Cave fauna. In addition to the larger percentage of extinct forms from Hawver Cave, an age difference between the fauna from this locality and the fauna from Samwel Cave is suggested by the presence in the former of *Smilodon(?)*, *Mylodon* and a species of wolf near *Canis dirus,* and by the absence of *Preptoceras.* It is certain that the dissimilarity in faunas between Hawver Cave and Samwel Cave is nearly, if not fully, as great as between the faunas of Potter Creek Cave and Samwel Cave.

When contrast is made between Hawver Cave and Potter Creek Cave, we note that faunas from both localities are characterized by a greater number of extinct species than occur at Samwel Cave. In addition to *Euceratherium, Megalonyx* and *Nothrotherium,* which may be considered as typifying deposits of the Sierran foot-hill region, forms occurring in both these deposits and absent from Samwel Cave include *Mammut* and *Bison.* A canid species from Hawver Cave is apparently related to *Canis dirus,* a form found at Potter Creek Cave but absent from Samwel Cave. We note also the absence of *Preptoceras* from both deposits. The ground-sloth *Mylodon* and a sabre-tooth tiger are present at Hawver Cave but absent from Potter Creek Cave, while in the latter deposit are found *Arctotherium, Platygonus(?)*, and a camelid which does not occur at the former cave. The absence of the latter types would appear indicative of a difference in age between Hawver Cave and Potter Creek Cave. It suggests that Hawver Cave contains a slightly later fauna. On the other hand, the possibility remains that these faunas merely supplement each other and that approximately the same stage of the Pleistocene is represented. The ground-sloth *Nothrotherium* from Hawver Cave is believed to differ subspecifically from the Potter Creek Cave type.

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The presence of *Mylodon* and the sabre-tooth tiger in such large numbers at Rancho La Brea indicates that these forms flourished in California during at least a portion of the Pleistocene. They represent forms which evidently ranged widely over the state, not only over the Great Valley of California but into the foothill belts of the Coast Ranges and Sierra Nevada as well. Their absence from certain deposits should then be considered as of especial significance. The presence of these forms and the absence of *Oreamnos* from the Hawver Cave accumulation suggests that the fauna came somewhat more under the influence of the plains than did the fauna of either Potter Creek Cave or of Samwel Cave. It should also be remembered that Hawver Cave is situated some 150 miles south of the Shasta caves. The absence of grazing camels may be due to local conditions. It seems possible that were more material recovered from Hawver Cave, a still closer similarity to the Potter Creek Cave fauna would be found to exist.

The faunal differences existing between Hawver Cave and Potter Creek Cave are then to be attributed in part to a geographic separation of the deposits and in part to a difference in age. Both Hawver Cave and Potter Creek Cave contain types usually associated with earlier portions of the Pleistocene, but certain forms found in each deposit are absent from the other. Hawver Cave is distinctly nearer Potter Creek Cave in age than is Samwel Cave. Final judgment on the relative age of these accumulations can be given only when the time and space-limits of the genera involved in this problem can be more exactly stated for the Pleistocene.

COMPARISON OF THE HAWVER CAVE FAUNA WITH THE FAUNAS FROM PORT KENNEDY DEPOSIT AND CONARD FISSURE

The vertebrate remains from the Port Kennedy bone deposit of Pennsylvania have been described by E. D. Cope.[6] According to Osborn[7] this fauna is characterized by a great predominance of extinct forms, for "Out of a total of thirty-six genera ten are now extinct, and out of forty-seven identified species twenty-nine are now extinct (Mercer)."

The Hawver Cave fauna compares favorably with that from Port

[6] Cope, E. D., Vertebrate remains from Port Kennedy bone deposit, Jour. Acad. Nat. Sci. Phila., ser. 2, vol. 11, pp. 193–267, pls. 18–21, 1899.

[7] Osborn, H. F., The age of mammals in Europe, Asia and North America (N. Y., Macmillan, 1910), p. 470.

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Kennedy fissure in the relatively large number of forms which are extinct. It resembles the latter also in the presence of certain types. In the Pennsylvania deposit the ground-sloths form an important element of the fauna. Both *Mylodon* and *Megalonyx* are represented, the latter by a number of species. *Nothrotherium* is not recorded. *Mylodon* occurs in the Hawver Cave accumulation apparently associated with *Megalonyx*. *Nothrotherium* is, however, the principal member of the ground-sloth group found at this locality. The present known distribution during the Pleistocene limits the genus to California and Texas.

Sabre-tooth cats occur in both western and eastern fissure accumulations, as well as representatives of *Equus*, a bison, and a mastodon. Conspicuous differences between the two faunas rest in the absence from Hawver Cave of *Arctotherium*, *Tapirus* and peccaries of the genus *Mylohyus*, which are found in the Port Kennedy fissure. *Euceratherium* is present in the California cave and absent from the Pennsylvania deposit. In contrast to the occurrence of the latter form at Hawver Cave is the presence in the Port Kennedy deposit of a ruminant, *Teleopternus orientalis*. Affinity of this form to the muskox, *Ovibos*, is suggested by Matthew.

As a result of researches by Barnum Brown[8] on the Conrad fissure, a mammal assemblage is revealed from northern Arkansas indicative of a somewhat later phase of the Pleistocene than that represented by the faunas from Port Kennedy fissure and Potter Creek Cave. This fauna consists, according to Brown, of "thirty-seven genera and fifty-one species, of which four genera and twenty-four species are considered extinct." We note here a relatively much smaller number of extinct genera than is characteristic of Hawver Cave. The ground-sloths are totally lacking from the Conard fissure, but the sabre-tooth cats still occur. *Euceratherium* is absent but the musk-ox, *Symbos*, is recorded. *Mylohyus* is represented by several species in Conard fissure. This genus does not occur at Hawver Cave. The bison and mastodon are both absent from the former deposit.

The above comparisons indicate that the Hawver Cave fauna represents distinctly an older phase of the Pleistocene than is shown by the fauna from northern Arkansas. It resembles much more closely the fauna from the Port Kennedy fissure and is more nearly related in age to the latter than it is to the Conard fauna.

[8] Brown, B., The Conard fissure, a Pleistocene bone deposit in northern Arkansas: with descriptions of two new genera and twenty new species of mammals. Mem. Amer. Mus. Nat. Hist., vol. 9, pp. 155–208, pls. 14–25, 1908.

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COMPARISON WITH RANCHO LA BREA FAUNA

All the extinct genera from Hawver Cave, with the exception of *Euceratherium,* are known to occur also at Rancho La Brea. A closer agreement of the two faunas can be established, for in several instances there is specific identity of forms. *Mylodon harlani* occurring in the fissure deposit is known by very abundant material from Rancho La Brea. A puma considered as probably belonging to a new species is very closely related, if not specifically identical with, a large cat (*Felis daggetti* Merriam, J. C.) from the asphalt beds. From Hawver Cave a large canid is known which in several characters approaches *Canis dirus.* This species is the very common wolf of Rancho La Brea. In so far as the material allows of comparison, the bison from Hawver Cave is identical with that occurring in the asphalt deposits.

It is seen then that several species are in common to the two accumulations. A difference in faunas due to difference in environment is indicated by the presence of *Euceratherium* at Hawver Cave and the absence of this form from the asphalt. The relatively greater importance of *Nothrotherium* in the Hawver Cave fauna, as contrasted with *Mylodon,* is also considered as suggestive of an environmental difference. It is believed that the mammal assemblage living in the region of Hawver Cave during the Pleistocene included a greater number of plains types than did the Potter Creek Cave fauna. In this respect then the Hawver Cave fauna occupies a position between that of the latter and the fauna of Rancho La Brea. It may be remarked again that *Oreamnos,* the mountain goat, is absent from Hawver Cave but present in the Shasta deposit.

It is difficult at present to reach a definite conclusion regarding exact age relation of Hawver Cave and Rancho La Brea. Determination of the age of the asphalt beds depends foremost upon a knowledge of the entire fauna. This study is still under way, and much remains to be done. The present evidence would seem to suggest that the Hawver Cave fauna represents a stage of the Pleistocene similar to that indicated by the Rancho La Brea fauna. The accumulation of mammalian remains in the Eldorado fissure probably entailed a shorter time than did the deposition of materials at Rancho La Brea. It is currently assumed, however, that the time necessitated for accumulation of the vertebrate remains in the asphalt pits was also relatively short.

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COMPARISON WITH RECENT FAUNA

Mammals believed to live in the vicinity of the cave at the present time or known to have existed in this region within the past fifty years are given in the list below. They are for the most part characteristic of the Upper Sonoran life zone as recognized by California zoögeographers. The present list has been kindly furnished by Dr. Joseph Grinnell of the California Museum of Vertebrate Zoology.

List of Recent Mammals

Scapanus latimanus (Bachman) subsp.?	Central California mole
Myotis californicus californicus (Audubon and Bachman)	Little California bat
Pipistrellus hesperus merriami (Dobson)	Cañon bat
Eptesicus fuscus fuscus (Beauvois)	Large brown bat
Corynorhinus macrotis intermedius Grinnell, H. W.	Intermediate lump-nosed bat
Nyctinomus mexicanus Saussure	Mexican free-tailed bat
Ursus, sp.	California grizzly
Canis, sp.	Timber wolf
Canis ochropus ochropus Eschscholtz	California valley coyote
Urocyon cinereoargenteus californicus Mearns	California gray fox
Bassariscus astutus raptor (Baird)	California ring-tailed cat
Procyon lotor psora Gray	California coon
Mustela xanthogenys xanthogenys Gray	California weasel
Mustela vison energumenos (Bangs)	Pacific mink
Spilogale phenax phenax Merriam, C. H.	California spotted skunk
Mephitis occidentalis occidentalis Baird	Northern California striped skunk
Taxidea taxus neglecta Mearns	California badger
Lutra canadensis brevipilosus Grinnell	California river otter
Felis oregonensis oregonensis Rafinesque	Northwestern cougar
Lynx eremicus californicus Mearns	California wildcat
Reithrodontomys megalotis longicaudus (Baird)	Long-tailed harvest mouse
Peromyscus maniculatus gambeli (Baird)	Gambel white-footed mouse
Peromyscus boylei boylei (Baird)	Boyle white-footed mouse
Peromyscus truei gilberti (Allen)	Gilbert white-footed mouse
Neotoma fuscipes streatori Merriam, C. H.	Streator wood rat
Microtus californicus californicus (Peale)	California meadow mouse
Thomomys bottae leucodon Merriam, C. H.	White-toothed pocket gopher
Perognathus californicus californicus Merriam, C. H.	California pocket mouse
Dipodomys californicus Merriam, C. H.	California kangaroo rat
Citellus beecheyi beecheyi (Richardson)	California ground squirrel
Sciurus griseus griseus Ord	California gray squirrel
Castor subauratus Taylor	Golden beaver
Lepus californicus californicus Gray	California jack rabbit
Sylvilagus auduboni auduboni (Baird)	Sacramento cottontail

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Sylvilagus bachmani mariposae Grinnell and Storer	Mariposa brush rabbit
Cervus nannodes Merriam, C. H.	Dwarf elk
Odocoileus hemionus hemionus (Rafinesque)	Rocky mountain mule deer
Antilocapra americana americana (Ord)	Prong-horn antelope

The smaller carnivores and rodents present in the Pleistocene fauna of Hawver Cave are for the most part directly comparable to forms living in the vicinity of the caves at the present time. Unfortunately the rodent remains are not complete enough to furnish satisfactory evidence as to the life zone or zones represented by the fauna. In so far as known the rodents seem to reflect mainly the Upper Sonoran zone. As shown by Louise Kellogg[9] the greater number of rodents from Potter Creek Cave and from Samwel Cave are types found in the Transition and Boreal zones. The only characteristic representative of the latter zones to be found at Hawver Cave is *Aplodontia*, a rodent originally listed in the cave fauna by Furlong.

The larger mammals, such as the carnivores and ungulates, in possessing a more extensive geographic range are less likely to be characteristic of particular zones. They serve therefore as less delicate instruments for recording climatic changes by indicating the situation of life zones in a former period. Nevertheless they are excellent indicators of climatic fluctuations in the large.

In marked contrast to the Recent fauna is the presence in the Pleistocene assemblage of sabre-tooth cats, ground-sloths, euceratheres and the mastodon. Among the large ungulates were also present the deer, the bison and the horse. The only form of this group at present existing in the fauna is the deer, *Odocoileus*. The Recent dwarf elk and the prong-horn antelope are unrecorded in the cave deposit. Of the large carnivores the bears, dogs and cats occur in both the Pleistocene and Recent faunas but probably many of them are specifically distinct. An extinct species of puma is related to *Felis oregonensis hippolestes*.

[9] Kellogg, L., Pleistocene rodents of California, Univ. Calif. Publ., Bull. Dept. Geol., vol. 7, pp. 151–168, 1912.

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ECOLOGICAL CONSIDERATIONS

The foregoing comparisons between the Pleistocene fauna of Hawver Cave and the fauna now living in the vicinity of the fissure indicate that the conditions which prevailed during accumulation of the fossil material were for the most part similar to those now prevailing in this region. Then, as now, the region of the cave deposit was tenanted or at least traversed by plains and forest types. This mixture of forest- and plains-dwelling forms has been noted also by Sinclair for the Pleistocene fauna of Potter Creek Cave. Types frequenting or preferring the open plains are represented at Hawver Cave by *Equus, Bison,* and presumably by *Mylodon* and the sabre-tooth tiger. At Potter Creek Cave there occur besides *Equus* and *Bison,* a camelid and *Elephas;* while in Samwel Cave only *Equus* and *Elephas,* among the large forms, are indicative of such a habitat.

It is to be noted that the Pleistocene fauna of Hawver Cave came more under the influence of the plains environment than did the fauna of either Potter Creek Cave or Samwel Cave. This is suggested also by the absence of *Oreamnos* from the fissure in Eldorado County and the presence of this form in the Shasta caves. The present elevation of Hawver Cave above sea-level and the nature of the physiography in the vicinity of the deposit indicate that the region is not now inaccessible to forms living in the Great Valley of California. The fact that the prong-horn antelope and the dwarf elk are known to have ranged into this region, either during the present period or within the past fifty years, supports this contention. During the Pleistocene such plains-types as the bison, *Equus* and *Mylodon* were represented in the region. The range of *Mylodon* is restricted less by altitude and ruggedness of country than is usually supposed, for remains of this form have been found at great elevation in the Peruvian cordilleras.

Euceratherium, Megalonyx and *Nothrotherium* may be cited as characteristic of the belt in which Hawver Cave is situated. These forms probably ranged even higher in the Sierras than is indicated by their presence at Hawver Cave, but their size and weight no doubt prevented them from ranging to the summits. The ground-sloths *Megalonyx* and *Nothrotherium* apparently proved to be easy prey for the sabre-tooth tiger, for so far as known these forms were not protected by an armor of dermal ossicles. In contrast to the megalonychids is the genus *Mylodon,* in which type the ossifications in the skin are well developed and serve admirably to shield the animal from stabbing attacks of the machaerodonts.

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DESCRIPTION OF MATERIAL

INSECTIVORA

SCAPANUS, possibly n. sp.

A humerus and a ramus of the mandible without teeth are the only remains of moles found at Hawver Cave. Unfortunately the ramus is too fragmentary to be of any value in the specific determination of this form. The humerus, no. 21143, is slightly larger than humeri of *Scapanus latimanus occultus*. In posterior aspect no. 21143 differs from humeri of the Recent *Scapanus latimanus latimanus* and of *S. l. occultus* in possessing a longer entepicondylar notch. The head of the humerus is noticeably more compressed laterally in the cave specimen. It is possible that this specimen from Hawver Cave represents a form specifically distinct from *Scapanus latimanus*.

MEASUREMENTS OF HUMERUS, NO. 21143

Greatest length	*a*13.3 mm.
Greatest width	10.4

a, approximate.

CARNIVORA

CANIDAE

Both the wolf and coyote types are found in the fissure deposit. A calcaneum and a metapodial allow only of an approximate determination of the larger form. It is not known that the tarsal and metatarsal elements belong to the same individual.

CANIS, near DIRUS Leidy

A calcaneum, no. 21472, is longer than average specimens of *Canis dirus* from Rancho La Brea. The cave specimen (fig. 1) is larger also than the calcaneum of *C. pambasileus* examined. In certain characters, held in common by *C. dirus* and *C. pambasileus*, no. 21472 differs from both. Thus the tuber calcis is compressed laterally, which causes this process to be quite thin anteriorly. The large inner facet for the astragalus has the largest diameter transverse, while in the calcaneum of *C. dirus* and in that of *C. pambasileus* this diameter is fore and aft. In no. 21472 this facet is rather distantly situated with reference to the cuboid facet. The articulating face for the cuboid is subcircular in form and is of larger areal extent than that in *C. dirus*, especially in its anteroposterior diameter. In

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C. pambasileus, according to Merriam,[10] this face is "a little narrower transversely and more nearly quadrate in form . . . than in *C. dirus.*"

Metatarsal 3, no. 19937, is identical in size and shape with corresponding metapodials of *Canis dirus* from Rancho La Brea. Although

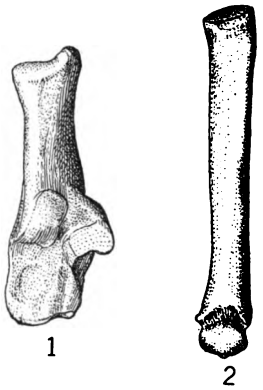

Fig. 1. *Canis,* near *dirus* Leidy. Calcaneum, no. 21472, × ½. Pleistocene of Hawver Cave, near Auburn, California.

Fig. 2. *Canis,* near *dirus* Leidy. Third metatarsal, no. 19937, × ½. Pleistocene of Hawver Cave, near Auburn, California.

this specimen (fig. 2) is absolutely shorter than the third metatarsal of *C. pambasileus,* the anteroposterior diameter of the proximal end and the width and thickness of the shaft at the middle are fully equal to the corresponding measurements in the Recent form. According to Merriam "The metatarsals of *C. dirus,* even where shorter absolutely than in *C. pambasileus,* are distinctly wider anteroposteriorly in the upper half of the shaft."

MEASUREMENTS

Calcaneum—no. 21472	
Greatest length	73.2 mm.
Greatest width	27
Metatarsal 3—no. 19937	
Greatest length	93
Anteroposterior diameter of proximal end	19.6
Transverse width at middle of shaft	10.5
Thickness at middle of shaft	8.9

CANIS OCHROPUS Eschscholtz

A skull from Hawver Cave, which is somewhat damaged and lacks the lower jaw, agrees in dimensions with skulls of the Recent *Canis ochropus* and is referred to that species. The California valley coyote

[10] Merriam, J. C., The fauna of Rancho La Brea, pt. 2, Canidae, Mem. Univ. Calif., vol. 1, p. 239, 1912.

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ranges into the foot-hill region of the Sierra Nevada at the present time. According to Joseph Grinnell[11] this form is found chiefly in the Lower and Upper Sonoran life zones, but may occur locally in the Transition zone.

MACHAERODONTINAE

SMILODON(?), sp.

The machaerodont cats are known from Hawver Cave only by the proximal third of a left fibula, no. 19913 (figs. 3*a*, 3*b*). It is of course impossible on such incomplete material to determine definitely the genus represented. The specimen is, however, so closely similar to the corresponding portion of the fibula of *Smilodon californicus*, occurring abundantly in the Pleistocene of Rancho La Brea, that there is but little hesitation felt in referring it to that form. The machaerodonts have not been recorded from either Potter Creek Cave or Samwel Cave in California, although known to occur in the Conard fissure of northern Arkansas[12] and in the Port Kennedy deposit of Pennsylvania.[13] The Hawver Cave fragment is then of particular interest in that it records for the first time the presence of the sabre-tooth tiger in cave faunas of this state.

In expansion of the head and thickness of the shaft, the cave specimen (figs. 3*a*, 3*b*) corresponds closely to fibulae of *Smilodon californicus* from Rancho La Brea and differs in these characters from the true cats. It exceeds, however, the average fibula of *Smilodon* from the asphalt beds in fore and aft diameter of head.

The forward extension of the head beyond the tibial facet is not so great as in the Recent California puma, *Felis oregonensis oregonensis*, but is greater than in the large Rancho La Brea lion, *Felis atrox*. The shaft of the fibula in *Smilodon* widens more rapidly to the proximal end to form the head than it does in the Rancho La Brea lion. The machaerodont fibula differs also from that of the lion in being not so greatly depressed on the medial side below the head, and in having a larger, grooved surface on the lateral side for insertion of the posterior portion of the tibio-fibular ligament. In the sabre-tooth tiger the insertion of the external lateral ligament probably did not extend distally as far along the antero-lateral margin of the

[11] Grinnell, J., A distributional list of the mammals of California, Proc. Calif. Acad. Sci., ser. 4, vol. 3, pp. 265–390, pls. 15, 16, 1913.

[12] Brown, B., The Conard fissure, a Pleistocene bone deposit in northern Arkansas: with descriptions of two new genera and twenty new species of mammals, Mem. Amer. Mus. Nat. Hist., vol. 9, pt. 4, 1908.

[13] Cope, E. D., Vertebrate remains from Port Kennedy bone deposit, Jour. Acad. Nat. Sci. Phila., ser. 2, vol. 11, 1899.

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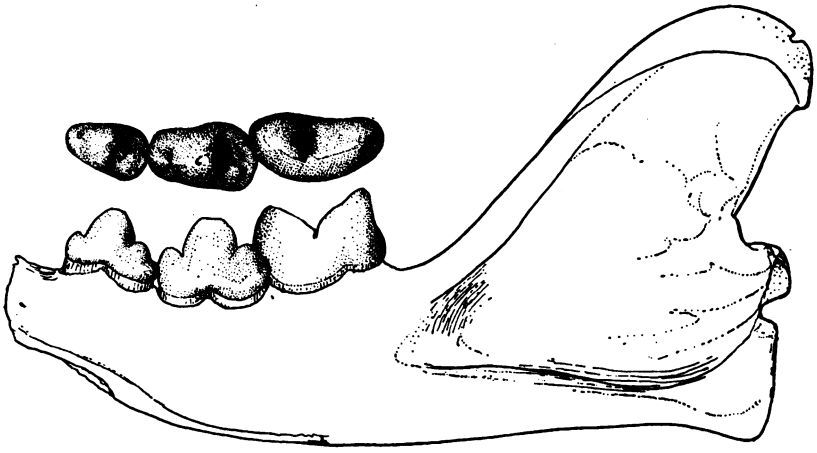
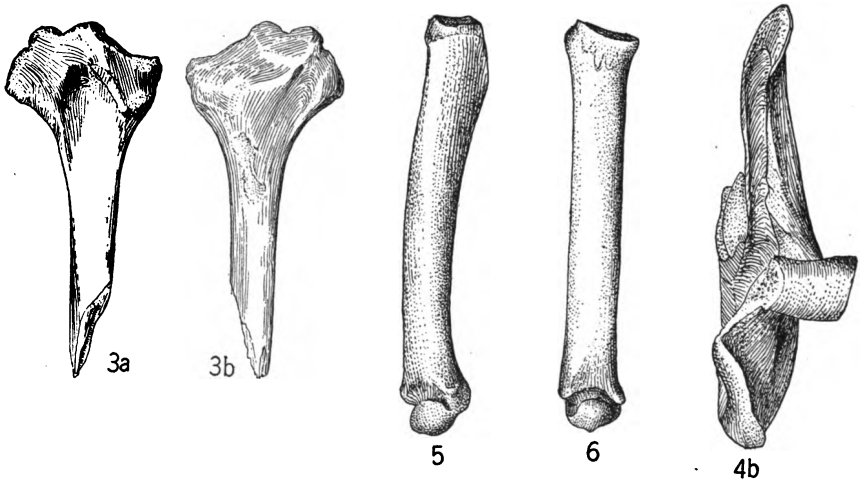
fibula below the head as in the Rancho La Brea lion. The fibula of the Recent African lion is very similar to that of *F. atrox* although much smaller in size.

MEASUREMENT OF FIBULAR FRAGMENT, NO. 19913

Greatest fore and aft diameter of head of fibula ..... 41.3 mm.



4a



Figs. 3*a* and 3*b*. *Smilodon(?)*, sp. Proximal end of fibula, no. 19913, × ½. Fig. 3*a*, outer surface; fig. 3*b*, inner surface. Pleistocene of Hawver Cave, near Auburn, California.

Figs. 4*a* and 4*b*. *Felis hawveri*, n. sp. Mandible, no. 10636, natural size. Fig. 4*a*, outer view of ramus, with occlusal view of cheek-teeth; fig. 4*b*, end view of ramus. Pleistocene of Hawver Cave, near Auburn, California.

Fig. 5. *Felis*, probably n. sp. Second metatarsal, no. 11019, × ½. Pleistocene of Hawver Cave, near Auburn, California.

Fig. 6. *Felis*, probably n. sp. Third metatarsal, no. 19925, × ½. Pleistocene of Hawver Cave, near Auburn, California.

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FELINAE

There are apparently two forms of the true cats represented in the cave fauna. The large type as indicated by a skull fragment, no. 19921, portions of two rami, no. 10637 and no. 19915, together with much skeletal material, is closely related to the large Recent puma, *Felis oregonensis hippolestes*. A somewhat smaller form, which can be distinguished from the Recent Pacific Coast puma, *Felis oregonensis oregonensis,* is represented by a broken ramus, no. 10636.

According to Joseph Grinnell, the Pacific Coast puma, *F. o. oregonensis,* ranges throughout California with the exception of the southeastern deserts. It is also found in all life zones of the state, though occurring perhaps most abundantly in the Upper Sonoran zone and in the Transition zone.

The hippolestes group, on the other hand, does not occur in the California region, but at the present time is found in the Cordilleras and to the east. During the Pleistocene a large puma of the *F. hippolestes* type is known to have occurred in California, being recorded from Potter Creek Cave and Samwel Cave in Shasta County and from Rancho La Brea in the southern part of the state.

FELIS HAWVERI, n. sp.

Type specimen.—No. 10636, Univ. Calif. Coll. Vert. Palae., an incomplete left ramus with P_3, P_4 and M_1 intact. From the Pleistocene deposit of Hawver Cave, near Auburn, California. The species is named in honor of the late Dr. J. C. Hawver.

A comparison between the cave specimen and some fifteen skulls[14] of the Recent *F. o. oregonensis* indicates a constant difference in shape of angle between the Pleistocene and Recent forms. There is no distinct angular process formed in no. 10636. In this specimen (figs. 4*a*, 4*b*) the posterior border meets the inferior border to form a right angle. In other words, the posterior border of the ramus below the condyle is straight and does not show the notching characteristic of jaws of Recent forms. Unfortunately the lateral portion of the condyle is broken away. The angle does not project beyond the posterior border of the condyle as it does in California representatives of the *F. oregonensis* group examined. Below the masseteric fossa the ramus is relatively deeper than in Recent forms.

[14] It should be remarked here that the skulls of the Recent Pacific Coast puma contained in the California Museum of Vertebrate Zoology were collected on Vancouver Island and at various localities in California. Future study of this material may show that at least two subspecies of the *F. oregonensis* group are represented in the area from which the present collections have been made.

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Judging from the wear to which the teeth have been subjected, no. 10636 belongs to a fully matured individual. The Hawver Cave specimen lies within the range of skull size of the Recent *F. o. oregonensis*. $P_{\frac{3}{3}}$ and $M_{\frac{1}{1}}$ are relatively heavy in the former specimen.

MEASUREMENTS OF NO. 10636

$P_{\frac{3}{3}}$, greatest anteroposterior diameter	12 mm.
$P_{\frac{3}{3}}$, greatest width	7
$P_{\frac{4}{4}}$, greatest anteroposterior diameters	14.7
$P_{\frac{4}{4}}$, greatest width	8.3
$M_{\frac{1}{1}}$, greatest anteroposterior diameter	17
$M_{\frac{1}{1}}$, greatest width	9
Depth of ramus behind $m_{\frac{1}{1}}$, measured normal to inferior border	22.7
Height of ramus from angle to coronoid	57.8
Distance from posterior end of $m_{\frac{1}{1}}$ to posterior end of condyle	51.2

FELIS, probably n. sp.

The larger of the two types of pumas from Hawver Cave resembles closely the Recent *Felis oregonensis hippolestes*. In so far as structures can be compared, it also bears a close similarity to the Pleistocene forms from Potter Creek Cave and Samwel Cave. Specimens from the latter localities have been referred to the Recent *F. o. hippolestes*. A fairly well preserved skull without mandible from Samwel Cave furnishes perhaps the best material from the fissure deposits of California representing a form near the *F. hippolestes* type.

A portion of a skull, no. 19921, from Hawver Cave, agrees very closely with the corresponding part in the Samwel Cave skull. In this specimen the infraorbital foramen resembles in size that in the Samwel Cave skull, and is relatively much smaller than in skulls of *F. o. oregonensis*. The postorbital process of the frontal is somewhat stouter in the Hawver Cave specimen.

In no. 19921 the teeth are larger and heavier than in skulls of *F. o. oregonensis*. The upper carnassial in the Hawver Cave fragment approximates the corresponding tooth of the Samwel Cave specimen in maximum length of crown. It exceeds in this measure the carnassials in male individuals of the Recent *F. o. hippolestes*. According to C. Hart Merriam,[15] in Recent specimens $P^{\frac{4}{4}}$ varies in length of crown from 23 mm. to 25 mm. (mean 24) in males, and from 20.2 mm. to 22.5 mm. (mean 21.6) in females.

[15] Merriam, C. H., Preliminary revision of the pumas (*Felis concolor* group), Proc. Wash. Acad. Sci., vol. 3, p. 588, 1901.

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The mandible of the fossil species as represented by specimens 10637 and 19915 is larger and C, $P_{\bar{4}}$ and $M_{\bar{1}}$ are heavier than in the Recent California puma. $P_{\bar{4}}$ and $M_{\bar{1}}$ are heavier than the corresponding teeth in lower jaws nos. 3819 and 3744 from Potter Creek Cave. The Hawver Cave specimens are referable possibly to male individuals.

A satisfactory comparison with the large puma known from Rancho La Brea[16] on basis of skull material can as yet not be made, as the latter form is known only by a portion of the jaw almost entirely absent in the Hawver Cave specimens. The width of the ramus just anterior to the masseteric fossa is approximately the same in both forms.

MEASUREMENTS OF DENTITION

No. 19921	
P^3, anteroposterior diameter	17.4 mm.
P^3, greatest transverse diameter	9.3
P^4, anteroposterior diameter	25.8
P^4, transverse diameter	12.3
No. 19915	
$M_{\bar{1}}$, anteroposterior diameter	19.2
No. 10637	
$M_{\bar{1}}$, anteroposterior diameter	19.2

Several metapodials are apparently to be associated with the skull material of the larger cat from Hawver Cave.

Metacarpal 5 resembles very closely the corresponding element in the California puma. In both forms, the tuberosity of the proximal end is less prominent than in *Felis atrox* and in *F. leo*. The lateral tuberosity is flattened, while in the African lion and in the large lion from Rancho La Brea it is rounded. At a distance from the proximal end equal to three-fourths of the total length of the metacarpal, a small tubercle is situated on the posterior side of the shaft. This is present also in the fifth metacarpal of *Felis oregonensis oregonensis*, but is absent in *F. atrox* and in *F. leo*.

Metatarsal 2, as represented by no. 11019 from Hawver Cave (fig. 5), is noticeably longer and somewhat heavier than the corresponding element of *F. o. oregonensis*. A second specimen, no. 21470, approaches more nearly the size seen in the Recent California puma. It is possible that the latter element belongs to the smaller of the

[16] Merriam, J. C., Recent discoveries of carnivora in the Pleistocene of Rancho La Brea, Univ. Calif. Publ., Bull. Dept. Geol., vol. 7, pp. 42–46, fig. 4, 1912.

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two specimens from Hawver Cave. The medial and posterior faces of the cave metapodials are less curved longitudinally than in the Recent form.

In end view the lateral border of the proximal articulating surface is concave as in the puma, while in *Felis atrox* and in *F. leo* this border tends to straighten. In *F. atrox* the lateral surface of metatarsal 2 reaches its smallest anteroposterior extent well below the middle of the metapodial. In the second metatarsals from Hawver Cave as well as in those of the Recent California puma the anteroposterior diameter rapidly diminishes below the proximal end and for the greater part of the shaft remains the same. *Felis leo* in this respect is more like *F. atrox*. In the cave specimens and in those of *F. o. oregonensis* the lateral and posterior faces below the proximal end form an acute angle; in other words, the posterior lateral angle is well defined. In *F. leo* and particularly in *F. atrox* there is a more gradual rounding from lateral to posterior face without formation of a distinct angle between them. The anterior lateral facet articulating with metatarsal 3 is more deeply depressed distally than is the corresponding facet of *F. atrox*. In proportion to metatarsal 3 the second metatarsal, no. 11019, is relatively long as contrasted with the corresponding element in the Recent *F. o. oregonensis*. There is, however, no direct evidence that the two cave metapodials thus compared, belong to the same individual. Two individuals of somewhat different sizes may account for the relatively great length of metatarsal 2 in contrast to that of metatarsal 3.

Two specimens of metatarsal 3 are available. No. 19925 (fig. 6) and no. 19922 resemble very closely in size and shape the corresponding element in the Rancho La Brea puma. They are but slightly more slender than the metapodials from the asphalt beds. In no. 19922 from Hawver Cave the posterior lateral facet articulating with metatarsal 4 reaches the proximal articulating surface, thus indicating that the remoteness of this facet from the proximal face is not a reliable character distinguishing the puma from *Felis leo* and *F. atrox*.

In the fourth metatarsal, no. 19923, the proximal articulating face, as in corresponding metapodials of *F. o. oregonensis*, slopes anteriorly and laterally. In *Felis atrox* and in *F. leo* this surface slopes anteriorly and medially. The anterior medial articulating face for metatarsal 3 is directed more anteriorly and less to the medial side, thus differing from *F. atrox* and *F. leo* and resembling rather the Recent puma.

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In so far then as the metapodials can be compared the Hawver Cave and Rancho La Brea pumas are very closely related, if not identical specifically.

The remaining skeletal parts of this species from Hawver Cave consist mainly of limb elements. With the exception of their larger size as contrasted with *F. o. oregonensis,* these structures do not require special mention.

MEASUREMENTS OF METAPODIALS

Metatarsal 2—

	No. 11019	No. 21470
Greatest length	107.5 mm.	98.5
Transverse diameter at middle of shaft	12	11
Fore and aft diameter at middle of shaft	10.5	9

Metatarsal 3—

	No. 19925
Greatest length	108.2
Fore and aft diameter of proximal end	*a*20.2
Transverse diameter at middle of shaft	12.9
Fore and aft diameter at middle of shaft	10.6

Metacarpal 4—

	No. 21471
Greatest length	86
Fore and aft diameter of proximal end	14.5
Transverse diameter at middle of shaft	9.2
Fore and aft diameter at middle of shaft	9.7

a, approximate.

RODENTIA

NEOTOMA FUSCIPES Baird

Material, principally in the nature of isolated mandibles, occurring in the Hawver Cave collections indicates the presence of the wood-rat, *Neotoma fuscipes.* This form is living in the vicinity of the cave at the present time. The species is readily distinguished from *N. cinerea* in the structure of the first inferior tooth. In *N. cinerea* the anterior end or lobe is constricted off from the remainder of the tooth much more definitely than in *N. fuscipes.* This is due mainly to the greater depth of the most anterior re-entrant angle of the inner side. The remaining re-entrant angles on the inner side of the tooth are more open and cause the inner lobes to assume positions more nearly at right angles to the long axis. In *N. fuscipes* the lobes take a position oblique to the main axis of the tooth. In these characters the cave teeth approach *N. fuscipes* and differ from *N. cinerea.*

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The differences in the dentition as noted above relate only to forms in which the third lower tooth is just coming into function. They become less evident as trituration progresses.

MICROTUS, sp.

A fragmentary ramus without teeth is the only specimen of this genus available. In the cave specimen, no. 21460, the mental foramen approaches very closely the superior border of the mandible in its position. This character is true also for *Microtus montanus* of the Sierran region. No. 21460 differs from *M. montanus* and *M. mordax* in that the lower border of the angle approaches more the level of the inferior border of the horizontal ramus. It differs further from these forms in that the posterior end of the angle is in a vertical line with the posterior end of the condyle, in which respect it resembles more the *M. californicus* group.

On the external surface of the ramus the peripheral process over the base of the incisor is broken, but it was evidently prominent and apparently lies above the masseteric crest as in *M. montanus*. In *M. mordax* the prominence lies in the crest while in *M. californicus* the masseteric crest is continuous. The condyle is decidedly more slender than in *M. montanus* and approaches that in *M. mordax*. The internal dental foramen is situated very close to the inferior border of the condyle, while in *M. montanus, M. mordax* and *M. californicus* it lies well above the inferior margin.

At the present time *M. montanus* ranges from Upper Sonoran to Transition, while *M. mordax* is found in the Transition and Boreal zones. *Microtus californicus* has the greatest zonal range. This species ranges from the Lower Sonoran to the Canadian (Lower Boreal).

The specimen from Hawver Cave may represent a form specifically distinct from the groups living in the Sierran region today, but much better fossil material must be awaited before this can be definitely ascertained.

LEPUS, probably n. sp.

Very fragmentary material of the rabbit group is available. Fortunately among these remains are several specimens of the third lower premolar. According to Dr. L. R. Dice,[17] who has recently studied the Tertiary lagomorphs of the Great Basin region, important taxo-

[17] Dice, L. R., Systematic position of several American Tertiary lagomorphs, Univ. Calif. Publ., Bull. Dept. Geol., vol. 10, pp. 179–183, 1917.

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nomic characters can be recognized in $P_{\bar{3}}$. On the basis of structure of this tooth, the Hawver Cave material appears to pertain to a new species. Comparisons have been made with the corresponding tooth in skulls belonging to the Recent species *Sylvilagus auduboni, Lepus californicus, L. campestris,* and *L. washingtoni klamathensis.*

Specimen 21437 is the anterior portion of a ramus with incisor and $P_{\bar{3}}$ intact. In size and in length of lower diastema this jaw fragment is evidently to be referred to *Lepus* rather than to *Sylvilagus.* These characters serve also to distinguish no. 21437 from *L. w. klamathensis.* In enamel pattern $P_{\bar{3}}$ of the cave specimen approaches that in *Sylvilagus auduboni* most closely. The pattern differs, however, from that in the former by a deeper indentation of the outer anterior border of the posterior re-entrant angle, while internally this anterior border is less complex. In no. 21437 there is also a single deep indentation of the posterior border toward the inner side, which apparently distinguishes this form from *Sylvilagus auduboni.*

Contrasted with corresponding teeth of *Lepus californicus,* no. 21437 from Hawver Cave differs in greater complexity of enamel border of the posterior re-entrant angle, particularly in those characters already mentioned in a comparison of the fossil form with *Sylvilagus.* In no. 18758 Calif. Mus. Vert. Zool. the indentation of the outer, anterior border of the posterior re-entrant angle approaches closely in appearance that in the cave tooth. There is certainly a much greater similarity between no. 21437 and $P_{\bar{3}}$ of *L. californicus* than between the former and *L. campestris.*

Measurements of no. 21437

Length of lower diastema	22.8 mm.
$P_{\bar{3}}$, greatest anteroposterior diameter	3.2
$P_{\bar{3}}$, greatest transverse diameter	2.6

Edentata

The most conspicuous group of animals occurring in the Pleistocene deposit of Hawver Cave is that of the gravigrade edentates or ground-sloths. Both the Megalonychidae and the Mylodontidae are represented; the former family by skull and skeletal material of *Nothrotherium* and a single element doubtfully referred to *Megalonyx,* and the latter family by several characteristic structures referred to *Mylodon.*

It is interesting to note the relative abundance of these forms in the cave fauna as indicated by actual numbers of individuals and

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amount of material preserved. Of the genus *Nothrotherium* two individuals are known and this form is best represented in amount of skeletal material. Much of the rolled and otherwise weathered material belonging to the edentates seemingly pertains to this small ground-sloth. *Mylodon* is known only by three specimens, a tooth and two phalanges, while *Megalonyx* is questionably represented by a single phalanx. It is a significant fact that in both Potter Creek Cave and Samwel Cave, *Nothrotherium* and *Megalonyx* are the principal representatives of the Gravigrada. The genus *Mylodon* is conspicuous by its absence in these deposits. Again, from Mercer's Cave near the town of Murphys, Calaveras County, California, Sinclair has described *Megalonyx sierrensis*. Thus we see that in the cave accumulations of California, the megalonychid ground-sloths are by far the more important types present, while the mylodonts occur but rarely.

In contrast to the ossiferous accumulations in caves are those deposits containing remains of a typical plains fauna, or, at any rate, an assemblage in which the larger herbivores, usually associated with extensive stretches of level or rolling country, predominate. At Rancho La Brea, for example, the mylodont sloths greatly overshadow in numbers both *Nothrotherium* and *Megalonyx*. *Nothrotherium* occurs at that locality more abundantly than does *Megalonyx*. Thus the relation between mylodonts and megalonychids, so far as actual numbers are concerned, is exactly the reverse of that obtaining in the cave deposits. Again, in the Pleistocene fauna of the Fossil Lake Beds of eastern Oregon a number of forms are included, such as horses, camels and antelopes, which are to be associated with extensive open stretches of country. In this fauna *Mylodon sodalis* (*Mylodon harlani?*) occurs, but the megalonychid sloths are entirely absent.

MYLODON HARLANI Owen

Three specimens indicating the presence of mylodont sloths so closely resemble corresponding elements of *Mylodon harlani* from Rancho La Brea that they are determined as pertaining to this genus and species.

The cross-section of the first inferior tooth, no. 19891, from Hawver Cave, is almost identical with that of *Mylodon harlani* Owen as figured by Leidy. Actual measurements show, however, that the cave specimen is smaller in anteroposterior diameter and larger in transverse diameter. Unfortunately the first tooth in the type specimen is fragmentary and comparison is limited to the outline of the tooth.

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In size and shape the cave specimen (fig. 7) corresponds closely to teeth of *M. harlani* from Rancho La Brea. The latter from the asphalt beds shows some range of variation in shape, such variation easily including the stage indicated by the first inferior tooth in the type specimen. Curvature of the crown, inward twisting of the lower portion on the long axis of the tooth, and anterior and posterior beveling of the triturating surface are characters common to both forms. The tooth from Hawver Cave and no. 21453 from Rancho La Brea possess residual patches of cement enclosing the outer layer of dentine, and in both specimens the concentric undulating lines on the surface of the dentine are plainly seen.

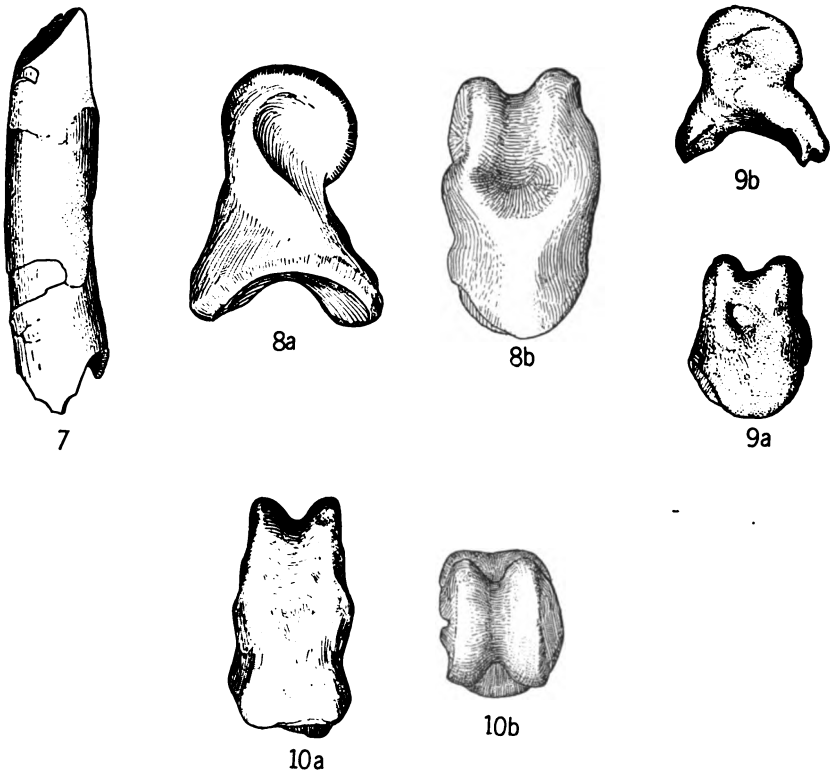

Fig. 7. *Mylodon harlani* Owen. First inferior tooth, no. 19891, outer view, × ½. Pleistocene of Hawver Cave, near Auburn, California.

Figs. 8*a* and 8*b*. *Mylodon harlani* Owen. Phalanx 2, digit 2, manus, no. 19892, × ½. Pleistocene of Hawver Cave, near Auburn, California. Fig. 8*a*, lateral view; fig. 8*b*, superior view.

Figs. 9*a* and 9*b*. *Mylodon harlani* Owen. Phalanx 2, digit 3, pes, no. 19893, × ½. Fig. 9*a*, superior view; fig. 9*b*, lateral view. Pleistocene of Hawver Cave, near Auburn, California.

Figs. 10*a* and 10*b*. *Megalonyx(?)*, sp. Second phalanx, no. 19863, × ½. Fig. 10*a*, superior view; fig. 10*b*, view of distal trochlea. Pleistocene of Hawver Cave, near Auburn, California.

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A second phalanx (figs. 8*a*, 8*b*), no. 19892, belongs to the second digit of the right anterior foot. It is larger than the average corresponding phalanx of *M. harlani* from Rancho La Brea and exceeds in total length the longest specimen from the asphalt. In the cave specimen, as well as in the phalanges from Rancho La Brea, the outer condyle of the distal trochlea is the larger and is separated from the inner condyle by a broad and rather shallow groove. The proximal articulating face in no. 19892 and in the specimens from Rancho La Brea consists of two concave facets separated by a thick median ridge, the outer facet being slightly larger than the inner one.

No. 21461 is a second phalanx of digit three, right posterior foot. This specimen (figs. 9*a*, 9*b*) differs from the preceding in being only one-half as large. It is very similar in general shape and size to the corresponding phalanges of *Mylodon harlani*. The thickened median ridge of the proximal articulating face is not as well defined as in no. 19892. The surface of the lower half of this ridge differs from the Rancho La Brea specimens in being concave. No. 21461 differs further from *M. harlani* in the wider overhanging process of the proximal face. The outer condyle of the distal trochlea, as in no. 19892, is the larger and is separated from the inner condyle by a groove which widens below. The surfaces of the distal condyles articulating with the ungual are semicircular in outline.

MEGALONYX(?), sp.

A phalanx, no. 19863, represents one of the second podial series. In size as well as in shape this specimen (figs. 10*a*, 10*b*) approaches more nearly the corresponding phalanx of *Megalonyx* than it does that of either *Mylodon* or *Nothrotherium*. The element in *Mylodon* which approaches no. 19863 most closely in structure is the second phalanx, digit two, manus. In both specimens the proximal articulating surface consists of two concavities separated by a thick median ridge which widens dorsally and ventrally. In *Mylodon*, however, the concavities have a greater dorso-ventral extent and the proximal extremity narrows more dorsally than in no. 19863 from Hawver Cave. Both elements are elongate anteroposteriorly with the distal end modified into a trochlea for articulation with the ungual. At the base of the trochlea both dorsally and ventrally the phalanx is not so deeply depressed as is the phalanx of *Mylodon*. A characteristic difference between the two phalanges is exhibited by the median groove of the distal trochlea. In *Mylodon* this groove is wide

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and relatively shallow, while in no. 19863 it is narrower and deeper. In this respect the cave phalanx resembles more closely corresponding phalanges of *Megalonyx* from Rancho La Brea.

The Hawver Cave specimen differs from all second phalanges of *Nothrotherium* known to the writer in a decidedly heavier construction. In this respect it is much more like the corresponding phalanges in *Megalonyx*.

MEASUREMENTS OF NO. 19863

Proximo-distal diameter through middle	58 mm.
Transverse diameter of proximal end	*a*30.5
Dorsoventral diameter of proximal end	*a*37
Greatest dorsoventral diameter of distal end	33.4

a, approximate.

NOTHROTHERIUM SHASTENSE HAWVERI, n. subsp.

Among the vertebrate materials recovered from Hawver Cave, the remains of *Nothrotherium* are undoubtedly the most conspicuous. Not only is the genus represented by skull structures, but by other parts of the skeleton as well. Comparison, especially of the dentition, can readily be made between the Hawver Cave form and that occurring in the other cave deposits and at Rancho La Brea. Where such comparisons have been made, it is found that the Hawver Cave form is typified by a M^5 slightly different from the corresponding tooth in Rancho La Brea specimens. This difference is held to be of subspecific importance and the new subspecies has been named in honor of the late Dr. J. C. Hawver.

Several *teeth* and a *skull* fragment are comparable in size to the corresponding parts in *Nothrotherium shastense* from Rancho La Brea. With the exception of M^5 the teeth resemble closely in shape those of the latter form.

A portion of the maxillary (fig. 11) with a fourth superior tooth in place is represented by no. 19864. In this specimen the two alveoli in front of the tooth are partly represented as well as a portion of the palate. The width of the palate measured between the alveoli of the third superior teeth is as great as in skulls of *N. shastense* from the asphalt beds. The crown of the fourth superior tooth is concave laterally. Its triturating surface is worn to a median groove which widens towards the inner side. The anterior edge of the wearing surface is beveled.

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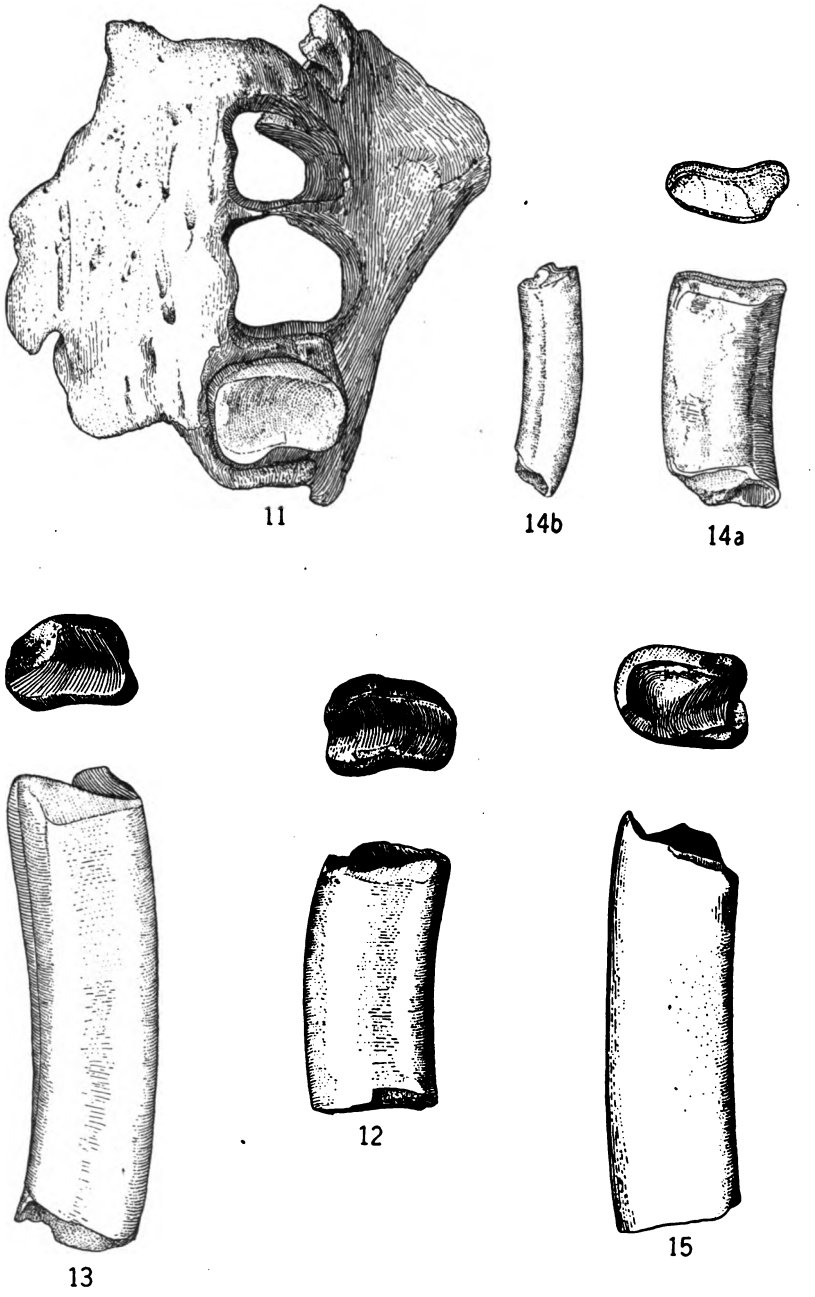

Figs. 11 to 15. *Nothrotherium shastense hawveri*, n. subsp. Fig. 11, portion of maxillary with M^4 of left side in place, no. 19864, inferior view; fig. 12, M^2 or M^4, no. 19860, posterior face with view of occlusal surface; fig. 13, M^3, no. 10634, posterior face with view of occlusal surface; fig. 14*a*, M^2, no. 21473, anterior face with view of occlusal surface; fig. 14*b*, M^2, no. 21473, view of outer side; fig. 15, M_2, no. 19867, posterior face with view of occlusal surface. All figures natural size. Pleistocene of Hawver Cave, near Auburn, California.

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A third or fourth superior tooth (fig. 12), no. 19860, does not differ essentially in general shape from the superior tooth in no. 19864. The triturating surface is worn more deeply to a median valley, while the posterior as well as the anterior border is beveled. The crown of the tooth is also longitudinally concave along the outer side. As in *N. shastense* this tooth possesses a concave posterior face, the inner and outer faces are grooved, and the anterior face is broadly convex. The tooth narrows toward the outer side.

The last upper tooth (figs. 14*a*, 14*b*) no. 21473, is wider transversely than most corresponding teeth from Rancho La Brea, being slightly larger in this direction than specimen 634 in the collections of the Museum of History, Science and Art of Los Angeles. It is relatively thinner anteroposteriorly than specimens from the asphalt beds. The shape of M^5 in the Rancho La Brea form is remarkably more strongly rounded inner side, an outer side which is directed more anteriorly and with a better defined longitudinal groove. The anterior face is convex toward the outer side and slightly concave toward the inner. It approximates the posterior face more closely toward the inner side than in M^5 from Rancho La Brea. The posterior face is deeply concave transversely. The triturating surface is beveled anteriorly. The crown of the tooth is longitudinally concave anteriorly and slightly so laterally.

A last inferior tooth (fig. 15), no. 19862, is comparable in size and shape to corresponding teeth of *Nothrotherium* from Rancho La Brea. It is larger than no. 8338 from Potter Creek Cave, but the latter evidently belonged to a younger individual. The tooth from Hawver Cave is characterized by the well-rounded inner face and the deep median groove of the outer face. The anterior and posterior faces are planes and are joined by the broadly rounded inner side. The faces join the outer side in well-rounded corners. The inner posterior border of the triturating surface is beveled as in *Megalonyx jeffersoni*.

MEASUREMENTS

No. 19864—

Width of palate between alveoli of M^2	24 mm.
Length from anterior end of M^2 to posterior end of M^4, alveolar measurement	48.5
M^4, greatest anteroposterior diameter at triturating surface	12.7
M^4, greatest transverse diameter at triturating surface	17

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No. 19860—	
M^2 or M^4, greatest anteroposterior diameter	12.9
M^2 or M^4, greatest transverse diameter	16.8
No. 10634—	
M^2, greatest anteroposterior diameter	11.9
M^2, greatest transverse diameter	16.4
No. 21473—	
M^2, greatest anteroposterior diameter	7.5
M^2, greatest transverse diameter	16.2
No. 19867—	
M_1, greatest anteroposterior diameter	14.3
M_1, greatest transverse diameter	16.2

With the exception of the cervical region, the *vertebral column* is represented by separate vertebrae in various stages of preservation. Only in the caudal series are several vertebrae directly associated.

No. 21476 (figs. 16*a*, 16*b*) represents the last sacral or first caudal vertebra, presumably of *Nothrotherium*. Unfortunately this specimen is very badly damaged, for approximately one-half only remains for identification. The centrum, in contrast to that of caudal vertebrae from Hawver Cave, is very broad and not of great depth. It is not possible to determine whether the centrum bore chevron-facets on the ventral surface, but it is presumed that these were absent. The transverse process is much expanded, with ventral surface decidedly concave and directed well forward. A broad groove extending from the neural canal to the ventral or posterior border lies adjacent to the posterior face of the centrum. This groove does not communicate with another canal coming from between the chevron facets as in caudal vertebrae of *Nothrotherium*. The neural arch encloses a spacious canal. The prezygapophysis is noticeably slender and does not possess an articulating facet on the inner face. On the inner posterior side of the prezygapophysis is a distinct pit.

A vertebra (figs. 17*a*, 17*b*, 17*c*) considered tentatively as the second of this series is comparatively well preserved. In this specimen the centrum is broad with dorsal border of anterior face straight. The posterior epiphysis is separated by a groove from the base of the neural arch and the transverse processes. The posterior face of the centrum is concave through the middle. The dorsal surface of the centrum is perforated by several large nutritive foramina. Four facets, articulating with the chevron bones, are situated on the ventral surface (fig. 17c), one facet at each lateral angle. The anterior and posterior pair of chevron facets are separated by a deep groove which

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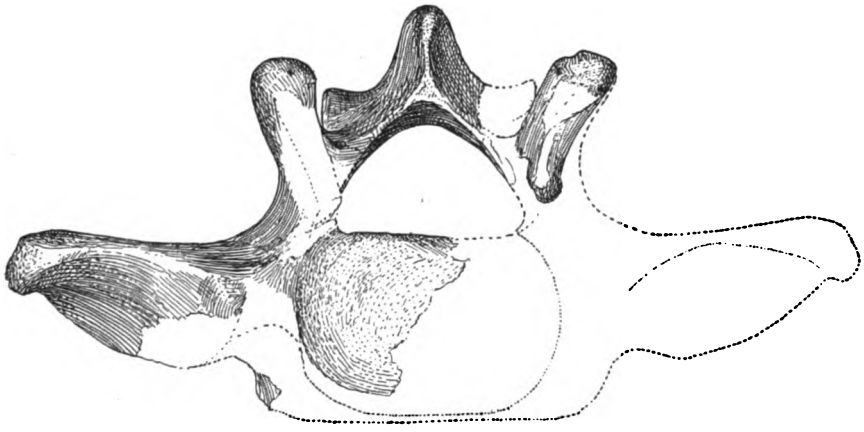
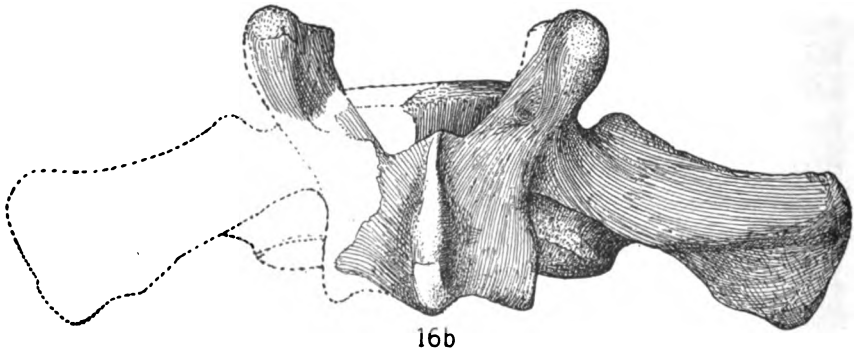
extends upward and posteriorly and connects with the groove lying between the dorsolateral border of the centrum and the base of the transverse process. The anterior chevron facets are more widely separated in median line and broader than the posterior facets. Several nutritive foramina pierce the middle of the ventral surface.

The transverse process resembles that in the vertebra of the Brazilian *Nothrotherium* figured by Reinhardt.[18] When viewed from the side the plane of the process is seen to slope approximately 28° from the horizontal. The pedicle of the neural arch is thick and sup-



16a



16b

Figs. 16*a* and 16*b*. (?)*Nothrotherium shastense hawveri*, n. subsp. Last sacral or first caudal vertebra, no. 21476, × ½. Fig. 16*a*, anterior view; fig. 16*b*, superior view. Pleistocene of Hawver Cave, near Auburn, California.

[18] Reinhardt, J., Kaempedovendyr-Slaegten Coelodon, Vidensk. Selsk. Skr., 5 Raekke, naturvidenskabelig og mathematisk Afhandl., vol. 12, pl. 2, figs. 4 and 5,

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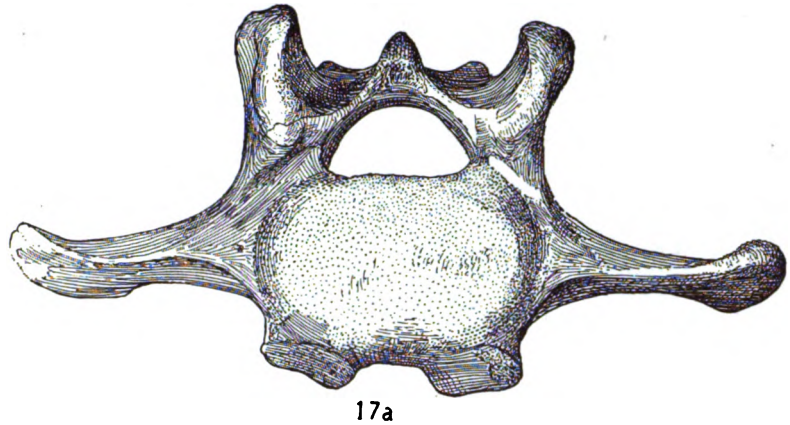
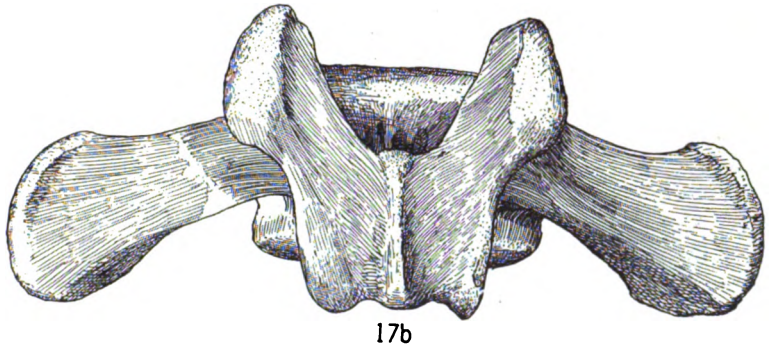
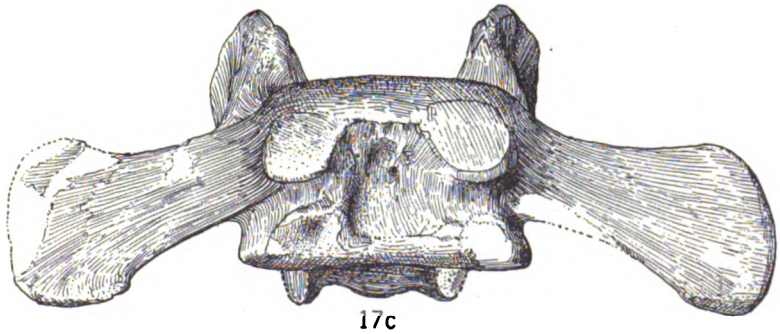


17a



17b



17c

Figs. 17*a*, 17*b*, and 17*c*. *Nothrotherium shastense hawveri*, n. subsp. Second(?) caudal vertebra, no. 21477, × ½. Fig. 17*a*, anterior view; fig. 17*b*, superior view; fig. 17*c*, inferior view. Pleistocene of Hawver Cave, near Auburn, California.

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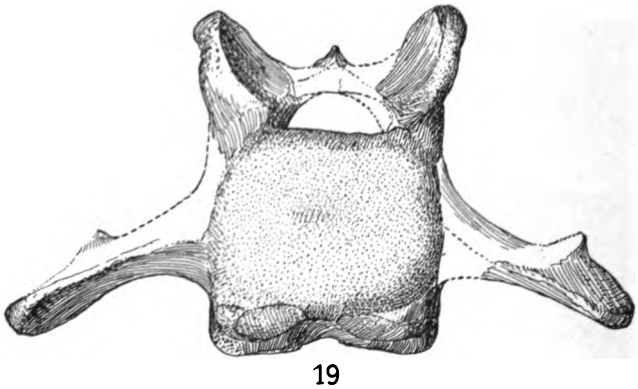
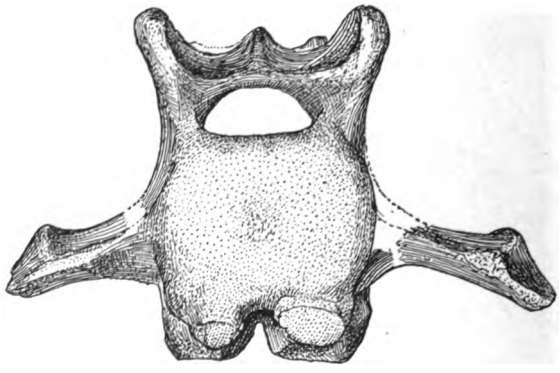
18



19



20

Figs. 18, 19, and 20. *Nothrotherium shastense hawveri*, n. subsp. Fifth, sixth, and seventh caudal vertebrae, nos. 21478, 21479, and 21480, × ½. Fig. 18, fifth vertebra, anterior view; fig. 19, sixth vertebra, anterior view; fig. 20, seventh vertebra, anterior view. Pleistocene of Hawver Cave, near Auburn, California.

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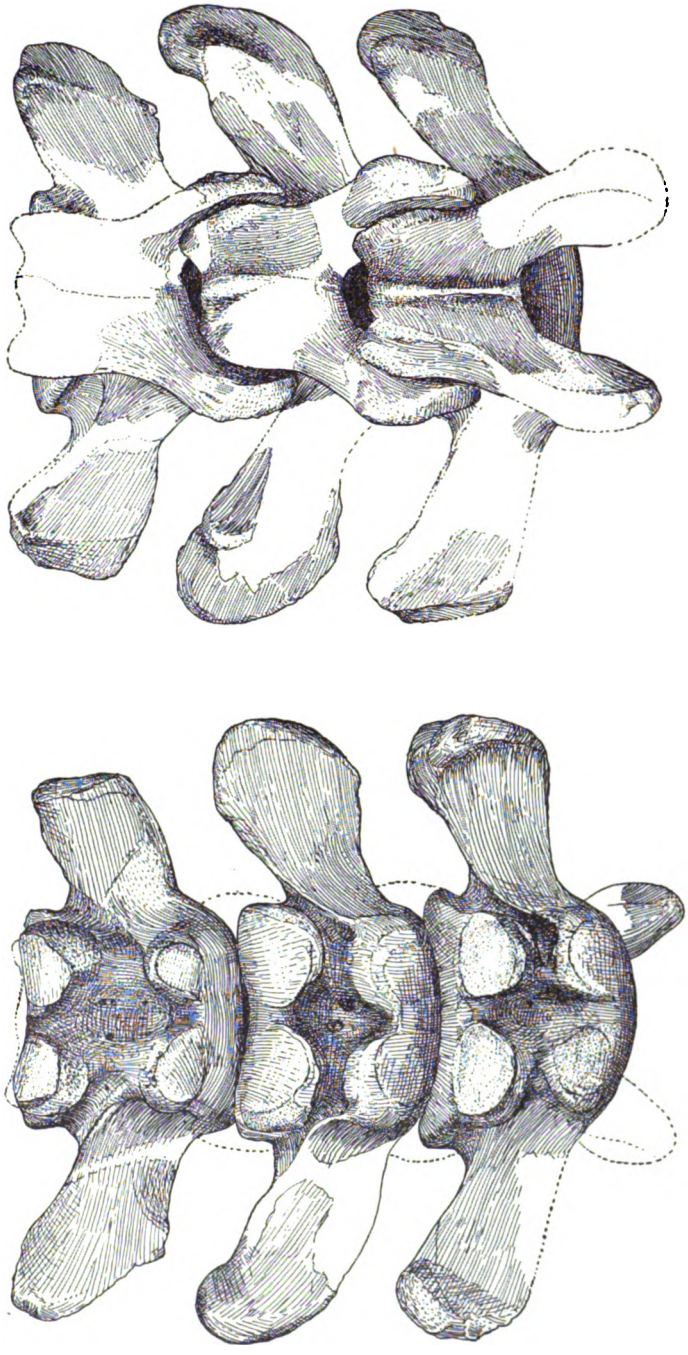

21a

21b

Figs. 21*a* and 21*b*. *Nothrotherium shastense hawveri*, n. subsp. Fifth to seventh caudal vertebra inclusive, nos. 21478, 21479, 21480, × ½. Fig. 21*a*, superior view; fig. 21*b*, inferior view. Pleistocene of Hawver Cave, near Auburn, California.

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ports a strong prezygapophysis. On the inner face of the latter a large articulating surface is directed mainly to the inner side.

Three of the caudal vertebrae have been determined as the fifth to seventh inclusive (see figs. 18, 19 and 20; also 21*a*, 21*b*). In this series the centra become progressively less broad, as indicated by the transverse diameter of the anterior face, and increase slightly in length. The groove extending backward and upward from between the anterior and posterior chevron facets of each side is well defined by a crest which extends from the pedicle supporting the anterior chevron facet to the base of the transverse process. This groove is present also in caudal vertebrae of the Miocene genus *Hapalops*. The anterior chevron facets are not nearly so far apart as in the second (?) caudal vertebra, and in the series from the fifth to seventh vertebra inclusive they decrease in size. In the seventh these facets are quite small as contrasted with the posterior facets, and are supported on rather prominent pedicles. The posterior facets are large and approximate each other closely in the median line in the sixth vertebra. In the seventh vertebra they are decidedly farther posterior to the forward facets than are those in the fifth and sixth vertebrae.

In the fifth caudal vertebra the outer third of the transverse process is sharply bent downward. This is particularly well shown on the right side of the specimen from Hawver Cave. The transverse processes of the two succeeding vertebrae become progressively broader anteroposteriorly and their outer portions are not bent downward so decidedly as in the fifth vertebra.

MEASUREMENTS OF VERTEBRAE

	No. 21476	No. 21477	No. 21478	No. 21479	No. 21480
Length of centrum	*a*50.7 mm.	50.4	50.1	50.2	51.4
Depth of centrum across anterior face	*a*47	50.8	48.4	49.4	46.4
Width of centrum across posterior face	.....	75.7	67.8	63.8	57.3
Depth of centrum across middle of posterior face	.....	52.5	50.5	50.3	47
Width across transverse processes	*a*226	206.4	163.5	165.4	*a*152
Greatest width across prezygapophyses	*a*96	91.8	.....	72.4	*a*67
Greatest width across postzygapophyses	*a*58	53	47.3	*a*45	.....
Height from ventral border of posterior face of centrum to top of neural spine	*a*112	*a*92	85.2	*a*82	*a*77

a, approximate.

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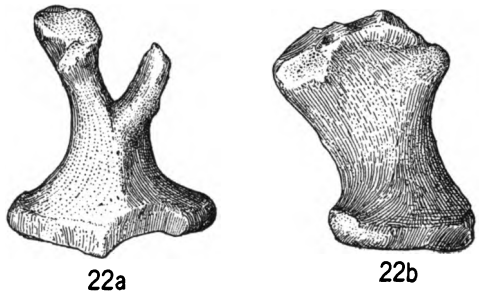
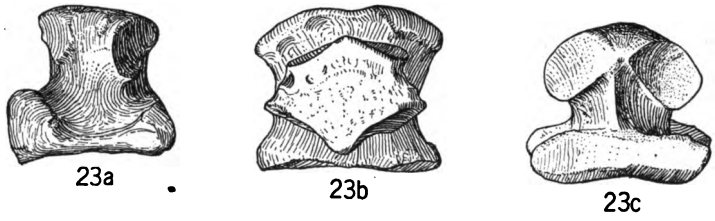
Reinhardt figures[19] a vertebra of the Brazilian *Nothrotherium* which he refers to the fourth or fifth of the caudal series. The fifth caudal from Hawver Cave differs from Reinhardt's specimen in the less prominent neural spine, broader posterior chevron facets, and shape of transverse process. In the vertebra from the Brazilian cavern this process is not deflected downward at the outer end, in which respect it is more like that in vertebrae of *Nothrotherium* situated more anteriorly in the caudal series.



22a 22b



23a 23b 23c

Figs. 22*a* and 22*b*. *Nothrotherium shastense hawveri*, n. subsp. Chevron-bone, no. 21474, × ½. Fig. 22*a*, anterior view; fig. 22*b*, lateral view. Pleistocene of Hawver Cave, near Auburn, California.

Figs. 23*a*, 23*b*, and 23*c*. *Nothrotherium shastense hawveri*, n. subsp. Sternal segment, no. 19890, × ½. Fig. 23*a*, lateral view; fig. 23*b*, inferior view; fig. 23*c*, end view. Pleistocene of Hawver Cave, near Auburn, California.

Specimen no. 21474, one of the *chevron-bones*, presumably of *Nothrotherium*, is worthy of note because of its peculiar shape. In contrast to the Y-shaped chevron-bones of *Mylodon*, the specimen (figs. 22*a*, 22*b*) from Hawver Cave has the distal end broadened considerably. The base forms a V with apex anteriorly and furnishes a fully adequate support for the bone. Apparently the approximate X-shape of the chevron-bone is due to a fusion of two lateral pieces, each of which has a wide base. No. 21475 probably represents one of these lateral pieces. In no. 21474 there has not been an entire fusion

[19] Reinhardt, J., *op. cit.*, pl. 2, figs. 4 and 5, 1878.

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of parts, for extending vertically downward from the haemal trough and piercing the bone is a short canal which opens distally between the arms of the broad base. Only one of the arms, forming the sides of the haemal trough, is preserved in the Hawver Cave specimen and it bears an anterior and a posterior facet for the caudal vertebra.

It would appear from the chevron-bone preserved that the tail of *Nothrotherium* received better support than did that of a type like *Mylodon.*

MEASUREMENTS OF CHEVRON BONES

	No. 21474	No. 21475
Greatest depth	59.8 mm.	67.8
Greatest anteroposterior diameter of proximal end	45.5	43.7
Transverse diameter at middle	20.	19.6
Greatest transverse diameter of distal end	54.7	

The *sternum* is represented by several separate elements, one of which (figs. 23*a*, 23*b*, 23*c*) is well preserved. This specimen, no. 19890, resembles mesosternal segments of *Hapalops* very closely in shape. No. 19890 is decidedly smaller than mesosternal segments of *Mylodon.* The flattened dorsal portion of the specimen from Hawver Cave is practically square with concave lateral margins and thickened anterior and posterior ends. At one end there is some indication of articulating surfaces on the ventral side and toward each of the lateral margins. With these exceptions there are no large and distinctly defined facets present at the corners of the ventral surface for sternal ribs as in the mesosternal segments of *Hapalops* and *Mylodon.* The ventral head of the pawn-like segment possesses four facets articulating also with sternal ribs.

MEASUREMENTS OF STERNAL SEGMENT, NO. 19890

Greatest length of base	43	mm.
Greatest width of base	48	
Depth	40	
Greatest anteroposterior diameter of ventral head	30.7	
Greatest transverse diameter of ventral head	41.6	

Although the *humerus,* no. 10631, is but a trifle shorter than the corresponding element of *Megalonyx,* no. 21003, from Rancho La Brea, and shorter than specimens of *M. jeffersoni* described by Leidy, the shaft is comparatively very slender and the distal third much less expanded. *Nothrotherium* differs decidedly more from *Hapalops* in slenderness of shaft of the humerus than does *Megalonyx.* In anterior view, figure 24*a*, the head of the cave specimen is not as

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prominent as in the humerus of *Megalonyx* from the asphalt beds. The inner and outer tuberosities of the proximal end are separated from the head by well-defined grooves. Anterior to the middle of the head the tuberosities are connected by a relatively broader shelf than in *M. jeffersoni*. On the anterior face of the inner tuberosity is a deep groove which extends parallel to the shallow bicipital groove. This channel is lacking in the humerus of *Megalonyx*. There is no deep groove in the humerus of *Hapalops* available for comparison, but in this specimen a broad, shallow groove or depression extends obliquely downward and across the anterior surface of the internal tuberosity from its upper border.

The pectoral ridge is distinct along the greater part of the shaft, forming the antero-internal border above the middle of the humerus. In the Miocene genus *Hapalops* this ridge extends along the middle of the shaft. The eminence formed by the union of the pectoral and deltoid ridges is of much less height in the Hawver Cave specimen than in *Megalonyx*. In *Hapalops* the elevation of the distal end of the pectoral ridge is very pronounced. An entepicondylar foramen is present as in *Megalonyx* and in *Hapalops*. The ulnar portion of the distal trochlea resembles *Mylodon* and differs from *Megalonyx* in being approximately flat transversely and in sloping downward and inward from the middle of the trochlea, reaching slightly below the level of the radial portion. It is, however, distinctly convex anteroposteriorly as in *Megalonyx*.

MEASUREMENTS OF HUMERUS, NO. 10631

Greatest length	444. mm.
Width at tuberosities	*a*97
Least width of shaft	*a*45.5
Greatest width of distal expansion	*a*170
Width of distal trochlea	95.3

a, approximate.

An *unciform*, no. 22899, is nearly complete, lacking only the dorso-external portion which has been broken away. This has destroyed the greater part of the facet for metatarsal 5 as well as some of the cuneiform surface, but the remaining facets are well preserved.

When viewed from the proximal end (fig. 25*c*) the unciform of *Nothrotherium* approaches that of *Hapalops* rather more closely than does the unciform of *Megalonyx* in the expanse of bone at the ventro-external angle. The cuneiform surface does not form

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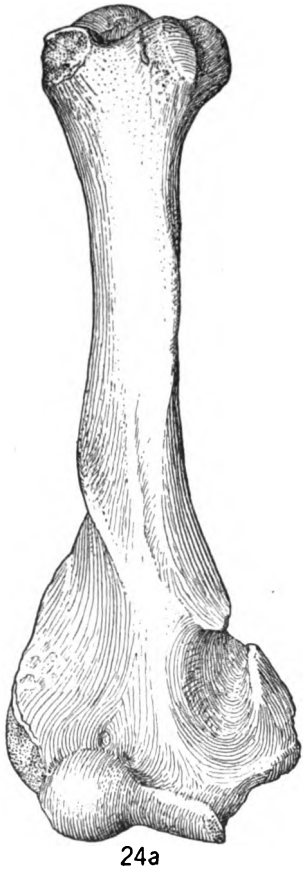
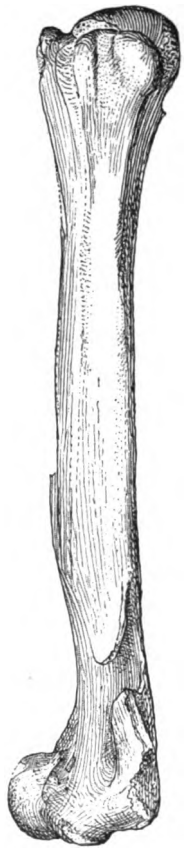
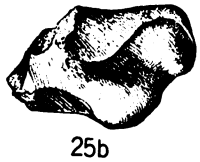


24a



24b

25a



25b

25c

25d

Figs. 24*a* and 24*b*. *Nothrotherium shastense hawveri*, n. subsp. Humerus. no. 10631, × ¼. Fig. 24*a*, anterior view; fig. 24*b*, inner view. Pleistocene of Hawver Cave, near Auburn, California.

Figs. 25*a* to 25*d*. *Nothrotherium shastense hawveri*, n. subsp. Unciform, no. 22899, × ½. Fig. 25*a*, superior view; fig. 25*b*, inferior view; fig. 25*c*, proximal view, fig. 25*d*, distal view. Pleistocene of Hawver Cave, near Auburn, California.

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internally such a distinct boss or knob as in *Megalonyx*. This is due in part to the fact that the articulating surface slopes away more gradually from the top of the knob to the dorsal margin of the unciform. In *Megalonyx* a shelf is formed at the base of the knob and the end of this shelf is the dorsal margin. The proximal knob differs further from *Megalonyx* and *Hapalops* in being curiously flattened along the inner side. On the inner side the facet for the magnum resembles that in *Megalonyx* and is relatively less extensive than that in *Hapalops*. Dorsally a small facet for the magnum, continuous distally with the facet for metacarpal 3, is not connected with the proximal articulating surface for the magnum as in the unciform, no. 22775, of *Megalonyx* from Rancho La Brea. The facet for metacarpal 3 (fig. 25*d*) is wide dorsally and narrows decidedly to the ventral side, thus resembling the corresponding feature in *Megalonyx jeffersoni* as figured by Leidy,[20] and differing from that in *Megalonyx* from Rancho La Brea. The widest portion of the facet differs from that in the latter genus in being deeply excavated, especially in an oblique line extending from the inner to the dorsal margin. In the unciform of *Hapalops*, the oblique groove traversing the facet dorsally is very much deeper than in *Nothrotherium* and notches the distal border of the carpal element. This deep groove is to be associated with a more extensive overlapping of metacarpal 3 upon the fourth metacarpal. In *Hapalops* the unciform joins with the external and internal sides of the overlapping processes, while in *Nothrotherium* articulation is with the external or true proximal face of the metacarpal.

In *Nothrotherium* the facet for metacarpal 4 differs from the corresponding surface in *Hapalops* in its much smaller size but resembles the latter in being deeply excavated. The facet in *Nothrotherium* is comparable in size to that in *M. jeffersoni*, but is decidedly smaller than in no. 22775 from Rancho La Brea. A small articulating facet, also for metacarpal 4, truncates the proximal portion of the boundary between facets for the third and fourth metacarpals.

The dorsal surface of the unciform (fig. 25*a*) differs from that in *Megalonyx* in being wider proximo-distally along the inner side, and the dorso-internal corner is not as prominent.

A *second metacarpal*, no. 19872, is very poorly preserved. The proximal end of this specimen is fragmentary and shows only portions of the articulating surfaces for trapezoid and trapezium. The former

[20] Leidy, J., A memoir on the extinct sloth tribe of North America, Smithson. Contrib. Knowl., vol. 7, pl. 8, fig. 13*b*, 1855.

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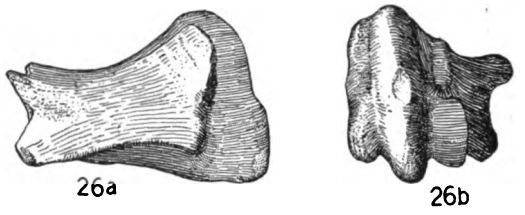
surface is sigmoid in dorso-ventral direction toward the external side. Internally this surface is flatter. The distal end bears a heavy carina with an offset along the lower portion of the inner side.

MEASUREMENTS OF SECOND METACARPAL, NO. 19872

Total length	*a*89 mm.
Depth of distal carina	43.4
Greatest width of distal end	27.6

a, approximate.



Figs. 26*a* and 26*b*. *Nothrotherium shastense hawveri*, n. subsp. Third metacarpal(?), no. 19861, × ½. Fig. 26*a*, lateral view; fig. 26*b*, view of distal end. Pleistocene of Hawver Cave, near Auburn, California.

The distal portion of a metapodial (figs. 26*a*, 26*b*), no. 19861, from Hawver Cave resembles most closely the corresponding part of the median metacarpal of *Nothrotherium*. The shaft at the middle is nearly square in section, and is more slender than that of the corresponding metapodial of *Megalonyx* or of *Hapalops*. Its distal end is also not so large as that in the latter genus. The carina is nearly straight, thus differing somewhat from that in either the Miocene form or in *Megalonyx*. Articulating offsets are present along the lower half of each side of the distal carina.

MEASUREMENTS OF METAPODIAL, NO. 19861

Greatest depth of distal end	45.8 mm.
Width of distal end	31

Contrasted with the *tibia* of *Megalonyx*, the specimen from Hawver Cave, no. 19965, is smaller but similar in general shape. As in the former genus and also as in *Hapalops* the proximal and distal extremities are much expanded, particularly the proximal end. The proximal half of the shaft below the articulating surface differs from that of *Hapalops* in being flatter and not as thick anteroposteriorly. This is distinctly seen in end view where in the tibia of *Hapalops* the anterior tuberosity is very prominent. Scott describes the proximal portion of the shaft of the tibia in *H. longiceps* as being trihedral in shape. In *Nothrotherium* it would appear that the portion of

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the tibia corresponding to the anterior tuberosity in *Hapalops* had been flattened down and to the outer side of the outer femoral articulating surface. In dorsal view this gives a very even anterior margin to the proximal surface. Judging from Leidy's figure[21] of the tibia of *Megalonyx jeffersoni* that genus differs decidedly from *Nothrotherium* in the well-developed anterior tuberosity, and in this respect resembles more the genus *Hapalops.*

At the proximal end the inner femoral articulating surface is large, subcircular and concave. Its antero-external portion is steeply inclined to form the inner side of the intercondyloid eminence. The latter spine is relatively not as prominent as in the tibia of *Hapalops,* but this difference may be due to the greater wear of the specimen from the cave. The fibular facet at the proximal end is more elongated than in *Megalonyx.* The shaft is thickest toward the medial border and narrows laterally. As indicated by Scott the distal end resembles that of *Hapalops.* Although prominent the inner malleolus is apparently in its width relatively not as broad as that of *Hapalops.* On the posterior surface there are two tendinal grooves, the external of which is quite broad while the internal one is much narrower. The articulating surfaces for astragalus and fibula extend obliquely across the distal end from the front backward and inward. The inner and outer surfaces for the astragalus are separated by an obscure ridge, and the distal spine is well developed as in *Hapalops.* The fibular facet is wide anteriorly and narrows behind. It perhaps does not extend so far up along the outer side of the tibia as in *Megalonyx.*

MEASUREMENTS OF TIBIA, NO. 19965

Greatest length measured along middle of shaft	*a*318 mm.
Greatest transverse width of proximal end	186.8
Least width of shaft	66.5
Thickness of shaft at middle	44
Greatest transverse width of distal end	138
Thickness of distal end	65.3

a, approximate.

The *fibula* of *Nothrotherium,* no. 19966, greatly resembles that of *Hapalops* in general shape. In proportion to the size of shaft, the fibula of the Pleistocene genus possesses relatively heavier extremities than that of *H. longiceps.* Contrasted with *Mylodon* the fibula of *Nothrotherium* is very much more slender in the region of the shaft

[21] Leidy, J., *op. cit.,* pl. 11, fig. 4.

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and is relatively much longer. The proximal expansion has its greatest diameter anteroposteriorly and bears along the inner side of the upper surface a tibial facet. At the posterior end of the proximal extremity and on the dorsal surface adjacent to the tibial facet is a small articulating surface. This facet apparently indicates the presence of a fabella along the outer side of the femur. In the second specimen, no. 19857, from Hawver Cave, representing only the proximal end of a fibula, this facet is lacking. The tibial side of the shaft is flattened while the remaining surface of this portion of the fibula is convex with the development of a rugose area along approximately the middle. The distal extremity is roughly pyramidal in shape with transverse diameter greater than the anteroposterior diameter.

MEASUREMENTS OF FIBULA, NO. 19966

Length	*a*286.2 mm
Greatest anteroposterior diameter of proximal end	75.5
Transverse diameter of proximal end	*a*65
Anteroposterior diameter at middle of shaft	24
Transverse diameter at middle of shaft	23.9
Anteroposterior diameter of distal end	59.6
Greatest transverse diameter of distal end	*a*92

a, approximate.

The *astragalus* of *Nothrotherium* resembles that of *Megatherium* in its shortness and the shape of the inner portion of the articulating surface for the tibia, but it is much smaller in the former genus. This element (figs. 28*a*, 28*b*) is apparently less like the corresponding structure of *Hapalops* in shape than is that of *Megalonyx*. The angle between the inner and outer divisions of the tibial surface is more distinct than in the astragalus of the Brazilian species described by Reinhardt, as well as in *Hapalops* and *Megalonyx*. Distally the two divisions of the tibial surface are separated by a deep, V-shaped notch as in Reinhardt's form. The fibular surface in the Hawver Cave specimen is relatively higher and not as long as in the Miocene genus. The articulating face for the fibula is less sharply separated from the tibial surface, especially in the distal region, where it gradually slopes downward to the calcaneal border.

The narrow and concave external calcaneal facet in the Hawver Cave specimen is more as in *Hapalops* than in *Megalonyx*. The distal half of this surface is deepened into a broad concavity sinking internally into the interarticular channel which obliquely traverses the

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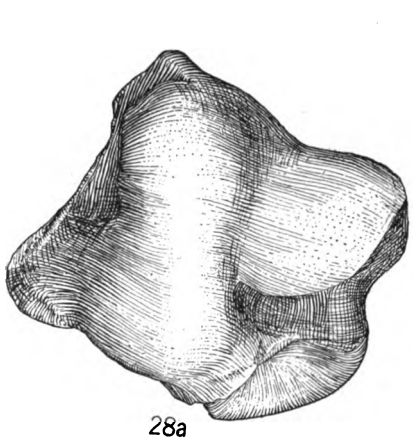

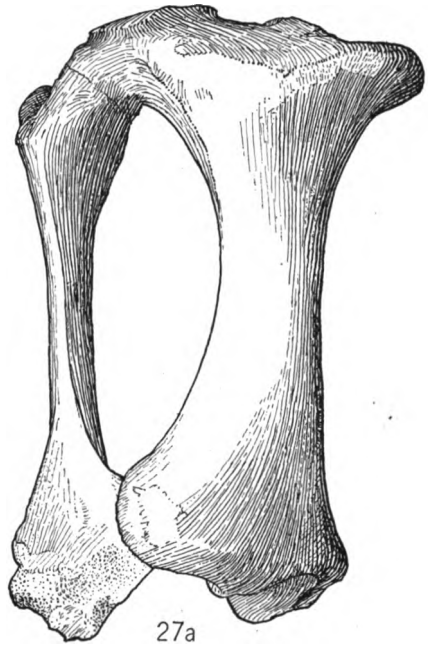

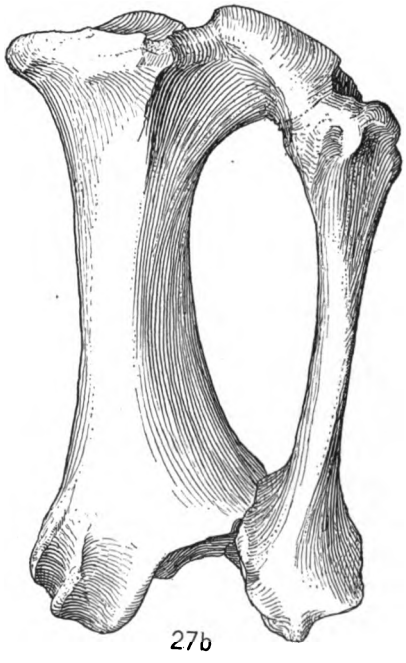

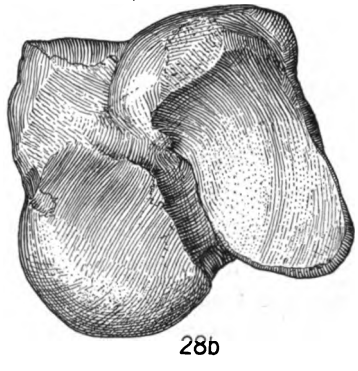

Figs. 27*a* and 27*b*. *Nothrotherium shastense hawveri*, n. subsp. Tibia and fibula, nos. 19965 and 19966, × ¼. Fig. 27*a*, anterior view; fig. 27*b*, posterior view. Pleistocene of Hawver Cave, near Auburn, California.

Figs. 28*a* and 28*b*. *Nothrotherium shastense hawveri*, n. subsp. Astragalus, no. 19856, × ½. Fig. 28*a*, proximal view; fig. 28*b*, distal view. Pleistocene of Hawver Cave, near Auburn, California.

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distal face of the astragalus. With a position internal, as in *Hapalops*, the facet for the sustentaculum borders the oblique interarticular channel just mentioned. It is continuous with the cuboid facet which in major part is situated on the palmar surface of the head. The neck is apparently much less conspicuous than in the Brazilian form. It is not constricted on the inner side as in the latter. The distal surface of the head is more deeply excavated for the navicular than in *Hapalops*.

MEASUREMENTS OF ASTRAGALUS, NO. 19856

Greatest anteroposterior diameter	101.6 mm.
Greatest transverse diameter across tibio-fibular surface, measured at a right angle to antero-posterior diameter	107.4
Depth of fibular surface at distal end	66
Transverse diameter of head across navicular depression	54.7
Greatest anteroposterior thickness of head	44

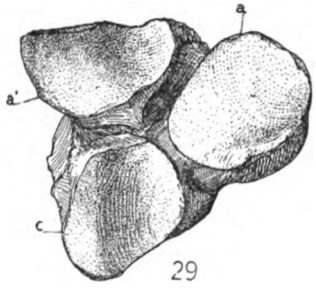

Fig. 29. *Nothrotherium shastense hawveri*, n. subsp. Articular end of calcaneum, no. 19871, × ½. *a* and *a'*, facets for astragalus; *c*, facet for cuboid. Pleistocene of Hawver Cave, near Auburn, California.

The *calcaneum* is represented by a fragment (fig. 29) showing the greater portion of the articulating end. In this specimen, no. 19871, the sustentaculum bearing the small facet for the astragalus is well preserved as is also the articulating surface for the cuboid, but the large external facet for the astragalus has been partly broken away.

The articulating end thus preserved, resembles that in the calcaneum of the Brazilian species of *Nothrotherium* illustrated by Reinhardt.[22] No. 19871 differs from the latter in having the sustentacular facet and the facet for the cuboid separated by a very narrow interspace and there is no indication of a bridge of bone connecting the two and lying adjacent to the median channel. The cuboid facet and the

[22] Reinhardt, J., *op. cit.*, pl. 5, figs. 3 and 4, 1878.

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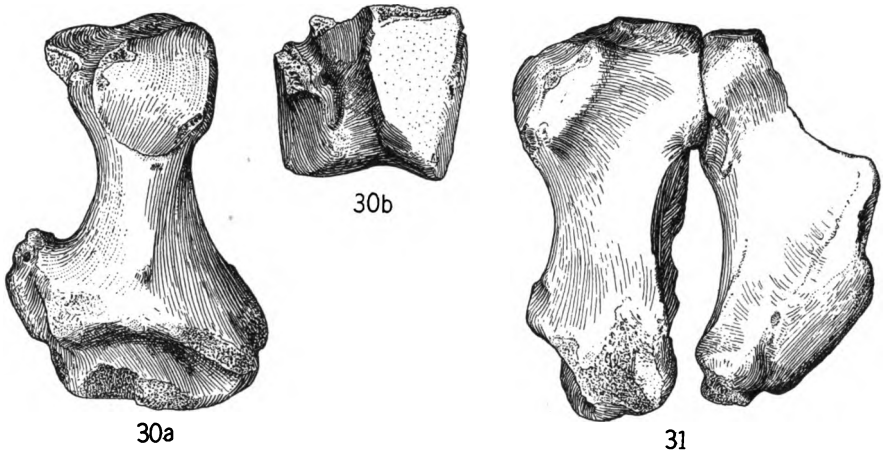
smaller of the two facets for the astragalus are of nearly equal size. The former facet is concave and slopes decidedly away from the internal channel. At the postero-inferior side of this facet the slender process, present in *Nothrotherium* but absent in *Megalonyx,* has been broken away. Unfortunately the large, external facet for the astragalus is not complete. This surface is sigmoid in its long axis.



Figs. 30*a* to 31. *Nothrotherium shastense hawveri,* n. subsp. Fourth and fifth metatarsals, nos. 19874 and 19875, × ½. Fig. 30*a,* fourth metatarsal, inner view; fig. 30*b,* fourth metatarsal, view of proximal end; fig. 31, fourth and fifth metatarsals, superior view. Pleistocene of Hawver Cave, near Auburn, California.

The *fourth metatarsal,* no. 19875, is but a trifle shorter than the corresponding metapodial of *Megalonyx jeffersoni.* The proximal end (fig. 30*b*) is nearly quadrate in shape, though unfortunately the lower portion of this extremity has been broken away in the specimen from the cave. A small facet at the dorso-internal angle of the proximal face, which is not represented in *Megalonyx* or in *Hapalops elongatus,* forms a lateral continuation of the articulating surface on metatarsal 3 for the ectocuneiform. This facet on metatarsal 4 is separated by a broad interarticular channel from the large facet for the cuboid of the proximal end. On the inner side the surface for the ectocuneiform is continuous with an articulating face for metatarsal 3. The latter facet is convex anteroposteriorly, and extends distally along the shaft farther than does the facet for metatarsal 5. The nearly flat facet for the cuboid is large and widens ventrally, *Nothrotherium* differing in the latter respect from *Megalonyx.* It is less extensive than in *Hapalops.* The facet for the cuboid

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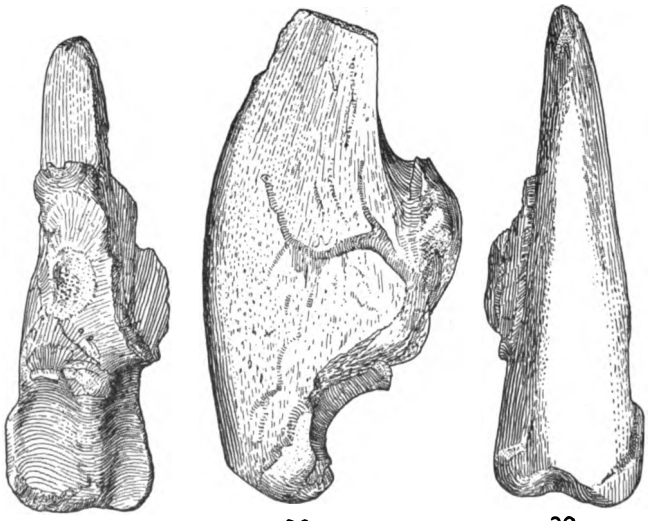
is separated from the large lateral facet for metatarsal 5 by a right angle. In *Hapalops* this angle is acute.

The shaft is well rounded internally, but the outer side is flattened more than in the fourth metatarsal of *Hapalops*. The distal extremity is greatly expanded dorsoventrally, but the carina is much less developed than in either *Megalonyx* or in the Miocene genus. The latter is bordered along the inner, lower half by an articulating offset. The dorso-external border of the metapodial ends distally in a large tuberosity which surmounts the carina. A small facet for a sesamoid is located at the ventral and external side of the carina.

A fragmentary *fifth metatarsal,* no. 19874 (fig. 31), was associated with the fourth metatarsal. The inner side of this specimen is flattened and sharply separated from the dorsal surface. At the proximal end of the inner surface is a rather large facet for the adjacent metapodial. A remnant of the articulating surface for the cuboid remains and is separated from the inner facet by a right angle. The distal end is tuberous and bears a small but distinct facet for the rudimentary toe. Unfortunately the entire lateral process has been broken away. The metapodial was, however, more expanded in this direction than that of *Megalonyx,* in which respect *Nothrotherium* is more like *Hapalops.*



Figs. 32*a*, 32*b*, and 32*c*. *Nothrotherium shastense hawveri*, n. subsp. Ungual, digit 3, pes, no. 19889, × ½. Fig. 32*a*, lateral view; fig. 32*b*, inferior view; fig. 32*c*, superior view. Pleistocene of Hawver Cave, near Auburn, California.

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MEASUREMENTS OF FOURTH METATARSAL, NO 19875

Greatest length	106.7 mm.
Greatest width of proximal end	49
Greatest depth of distal end	*a*67.7
Greatest width of distal end	40
Least depth of shaft	25

a, approximate.

No. 19889 (figs. 32*a*, 32*b*, 32*c*) is a rather poorly preserved *ungual phalanx* of the median digit of the pes. It is distinctly smaller than the corresponding phalanx of *Megalonyx jeffersoni*. The median ridge of the proximal articulating surface is very thick, and the proximal end of the phalanx above this ridge is deeply depressed.

UNGULATA

EUCERATHERIUM COLLINUM (?) Sinclair and Furlong

A right and a left superior molar, no. 21467 and no. 21468 respectively, indicate the presence of this peculiar bovid form, occurring so characteristically in the Pleistocene faunas of Potter Creek Cave and Samwel Cave in Shasta County. The range of this genus during the Pleistocene is thus extended some 150 miles to the southward in the foothill belt of the Sierras. With the exception of these occurrences in fissure deposits of California, *Euceratherium* is unknown from other Pleistocene faunas[23] of the state. This is noteworthy and suggestive particularly of those deposits representing faunas of the plains. *Euceratherium* seems then to be restricted in its range to mountainous or at least hilly country as already suggested by Sinclair and Furlong. In discussing the habitat of this form, Sinclair and Furlong[24] state as follows: "It is not probable that an animal of such size and weight was confined to the higher summits like the sheep and goats, but rather, as the specific name suggests, frequented the lower hills."

As stated by Sinclair and Furlong, the dentition of *Euceratherium* closely approaches that of *Ovibos*. The median external style in superior molars of *Euceratherium* tends to be more acute than in *Ovibos*. The molars from Hawver Cave agree with *Euceratherium* in this respect as well as in their size. On the whole the superior

[23] An incomplete horn in the palaeontological collections of the University of California apparently of *Euceratherium*, was secured a number of years ago from the Klamath River in Siskiyou County, California (loc. 3346).

[24] Sinclair, W. J., and Furlong, E. L., Euceratherium, a new ungulate from the Quaternary caves of California, Univ. Calif. Publ., Bull. Dept. Geol., vol. 3, p. 416, 1904.

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teeth of *Euceratherium* are very similar to those of *Preptoceras,* and isolated molars, as for example those from Hawver Cave, may perhaps with equal propriety be placed in either of the two Pleistocene genera of California. As noted, however, by Furlong,[25] the superior molar in *Preptoceras* possesses a minute style which is situated in the angle between the inner crescents. This style is absent in the Hawver Cave teeth.

MEASUREMENTS OF TEETH

Left superior molar, no. 21468, anteroposterior diameter	27.3 mm.
Right superior molar, no. 21467, anteroposterior diameter	*a*27.3

a, approximate.

BISON, sp.

A number of well-worn premolar teeth are referable to an old individual of *Bison.* In shape and size as well as in outline of enamel pattern the specimens are similar to corresponding teeth of *Bison antiquus* from Rancho La Brea.[26] In so far as indicated, the bison remains from the fissure deposit are not specifically separable from *B. antiquus* of the asphalt beds, and may represent the same type.

MEASUREMENTS OF TEETH

P^2, no. 21465, anteroposterior diameter	19.6 mm.
P^2, no. 21465, transverse diameter	15.8
P^2, no. 21463, anteroposterior diameter	22
P^2, no. 21463, transverse diameter	22.7
P^4, no. 21462, anteroposterior diameter	18
P^4, no. 21462, transverse diameter	25.2

SUMMARY

A detailed study has been made of the Pleistocene fauna secured from Hawver Cave. This fissure deposit is located in Eldorado County, California, five miles east of Auburn and approximately 150 miles to the southeast of Potter Creek Cave and Samwel Cave in Shasta County.

The age of the Hawver Cave deposit is determined as Pleistocene on the basis of presence in the fauna of typical Pleistocene genera, as *Smilodon(?), Nothrotherium, Megalonyx(?), Mylodon* and *Euceratherium.* This age is indicated also by the percentage of extinct species occurring in the fauna.

[25] Furlong, E. L., Preptoceras, a new ungulate from the Samwel Cave, California, Univ. Calif. Publ., Bull. Dept. Geol., vol. 4, pp. 163–169, pls. 24–25, 1905.

[26] Chandler, A. C., A study of the skull and dentition of *Bison antiquus* Leidy, with special reference to material from the Pacific Coast, Univ. Calif. Publ., Bull. Dept. Geol., vol. 9, pp. 121–135, 1916.

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Of the twenty-four species of mammals known from Hawver Cave, twelve or half the number of forms present are extinct. The percentage of extinct species of Hawver Cave is thus relatively greater than that of either Samwel Cave or Potter Creek Cave.

A comparison of the faunas from the three principal caves of California shows that Potter Creek Cave possesses the greatest number of extinct genera, namely seven. Hawver Cave follows next with six genera, while four extinct genera are known from Samwel Cave. On this basis it would appear that Potter Creek Cave contains the oldest mammalian assemblage with Hawver Cave approaching it closely in age, while Samwel Cave is somewhat younger than either of the other two. Three extinct genera are common to the three caves, namely, *Nothrotherium, Megalonyx* and *Euceratherium.* The presence of the ground-sloth *Mylodon* and of a sabre-tooth tiger at Hawver Cave is unique in that it records for the first time the occurrence of these forms in cave deposits of California. The faunal differences existing between Hawver Cave and Potter Creek Cave are to be attributed in part to geographic separation of the deposits and in part to a slight difference in age.

The Hawver Cave fauna represents distinctly an older phase of the Pleistocene than is indicated by the fauna from the Conard fissure of northern Arkansas. It resembles more closely the fauna from the Port Kennedy deposit of Pennsylvania and is more nearly related in age to the latter than it is to the Conard fauna.

During Pleistocene time the region about Hawver Cave was occupied by a fauna consisting of forest and plains dwelling forms, just as to-day the region is characterized to a certain extent by a mixture of these types. The animals themselves have changed in the interim. Within the Recent period wild horses, bison, mylodont sloths and sabre-tooth cats are no longer ranging over this region and over the Great Valley of California to the west. In the modern fauna, forms typical of the plains are represented by the prong-horn antelope and the dwarf elk. The absence of *Oreamnos,* the mountain goat, from the Hawver Cave deposit indicates also that the fauna from this locality came primarily under the influence of an environment such as exists at the present day along the borders of the Great Valley of California. *Euceratherium, Megalonyx* and *Nothrotherium* appear to have been characteristic of the foothill belt of the Sierra Nevada during Pleistocene time.

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BULLETIN OF THE DEPARTMENT OF
GEOLOGY
Vol. 10, No. 25, pp. 517-521 September 4, 1918

EVIDENCE OF MAMMALIAN PALAEONTOLOGY RELATING TO THE AGE OF LAKE LAHONTAN

BY
JOHN C. MERRIAM

UNIVERSITY OF CALIFORNIA PRESS
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EVIDENCE OF MAMMALIAN PALAEONTOLOGY RELATING TO THE AGE OF LAKE LAHONTAN[1]

BY
JOHN C. MERRIAM

Considering the importance of the deposits of Lake Lahontan in Pleistocene history of North America, it is surprising that exceedingly little palaeontologic evidence as to age of these beds has been obtained up to the present time. The mammal material available to Russell[2] in the course of his exhaustive study of these deposits consisted of a very few specimens representing four forms, for only one of which a specific determination has been suggested. The remains known to Russell represented an elephant, a horse, a bison, and a camel. A spearhead, found embedded in strata presumed to be of Lahontan age, was also reported. All of the forms known from the Lahontan were assumed to occur in the upper portion of the lake beds series and to have been buried subsequent to the "intermediate stage" of Russell.

Of greater importance than the scattered mammal bones secured in the Lahontan beds by Russell is a small collection obtained in 1914 by Professor J. C. Jones of the University of Nevada,[3] from deposits occurring at Astor Pass, four miles west of Pyramid Lake, and considered to represent Lahontan terraces. In the gravels of these deposits Professor Jones secured remains representing three or four mammals. One species is clearly determinable as *Felis atrox,* the largest known member of the true cat group. A second is a camel near *Camelops,* not differing noticeably from *Camelops hesternus,* well

[1] Read before the American Geographical Society, at New York City, December 29, 1916.

[2] Russell, I. C., U. S. Geol. Surv. Monographs, vol. 11, p. 238, 1885.

[3] See Merriam, J. C., Univ. Calif. Publ. Bull. Dept. Geol., vol. 8, pp. 377–384, 1915.

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known in the Pleistocene deposits of Rancho La Brea. A considerable part of a skull represents a horse, in which the dentition is slightly different from that of the Rancho La Brea *Equus occidentalis,* and approaches in some respects that of *E. pacificus* of the Fossil Lake Pleistocene of eastern Oregon. A single separate upper molar tooth of a horse from the same deposit is nearer in type to *E. occidentalis.*

A third important collection representing Pleistocene mammal faunas of the Great Basin province is the material secured by Buwalda[4] in the deposits of Manix Lake, a small body of fresh water which formed in the Mohave Desert region, in Pleistocene time. The Manix collection includes six species of mammals and one or more species of birds, together with four types of fresh-water mollusks. Of these forms the mammals include: (1) a large horse certainly *Equus;* (2) a somewhat smaller horse; (3) a large camel; (4) a small camel; (5) a fragment representing a proboscidean; (6) an antelope of unknown species.

The conditions which governed expansion of the lake in which the Manix deposits were formed resemble in a manner those which controlled variation of Lake Lahontan, as described by Russell. It is possible that the climatic changes which influenced Lake Manix are identical with those reflected in Lahontan history, and the Manix fauna may be of the same stage as that of Lahontan.

A fourth Pleistocene fauna from the Great Basin province is that of Fossil Lake in eastern Oregon, obtained in sandy deposits, the stratigraphic relations of which are not satisfactorily described. There has been some mingling of Recent and Pleistocene remains in the lists of material secured from this locality; but after all necessary subtractions are made, one of the most important Pleistocene mammal and bird faunas of America remains, including a large number of mammals and over fifty species of birds.

Evidence as to the age of the Fossil Lake fauna is to a certain extent contradictory. According to Gilbert[5] and to Russell, the stage of accumulation of the Fossil Lake deposits is approximately that of Lake Lahontan and Lake Bonneville. Gilbert considered that the highest level of Lake Bonneville corresponded approximately to the last stage of advance of the Wasatch glacier. Similar evidence seems to be furnished by the relation of the highest level of Pleistocene Lake

[4] Buwalda, J. P., Univ. Calif. Publ. Bull. Dept. Geol., vol. 7, pp. 443–464, 1914.

[5] Gilbert, G. K., U. S. Geol. Surv. Monographs, vol. 1, p. 395, 1890; Russell, I. C., *op. cit.,* vol. 11, 1885.

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Mono to the lowest moraines of the glacier on the east side of the Sierras. If these suggestions are approximately correct, the last stage of Lahontan and Bonneville, approximating the stage of Fossil Lake, would perhaps correspond to the Wisconsin or last glacial epoch.

In his study of Lake Bonneville, Gilbert gave particular attention to the problem of age determination of the deposits and made careful comparison of the sediments of the Bonneville and Lahontan stage with those of Fossil Lake in south central Oregon. He considered that in the Fossil Lake region, "just as in the Bonneville and Lahontan basins, the physical relations indicate that the shore lines and lacustrine sediments are co-ordinate products of the same expansion of lake waters." He stated further that "each of the old lakes thus demonstrated stands witness to climatic oscillation, and their geographic relations leave no room for question that they pertain to the same climatic oscillation, and therefore have the same date."

The evidence of faunas as interpreted by Osborn and by Hay would fix the age of the Fossil Lake deposits as early Pleistocene. In this palaeontologic determination one of the most important arguments is the absence of bison remains from these deposits, which were evidently formed in an open plains region where bison would be expected to occur. This peculiarity is offset to some extent by the fact that the large wolves of the Fossil Lake beds seem to be exclusively of the modern timber wolf type. The great dire wolf, *Aenocyon dirus,* has not been recognized in the Fossil Lake fauna, although it is exceedingly abundant at Rancho La Brea and seems to be represented at Potter Creek Cave. Difference in the types of wolves might be due to the northern origin of the modern timber wolf, and to its restriction throughout Pleistocene time to the northern portion of the West Coast region. Within historic time the timber wolf has not been known in middle and southern California. This would not, however, account for its failure to overlap in range with *Aenocyon dirus* in the Great Plains region. Of the total Fossil Lake fauna 66 per cent of the mammals and 34 per cent of the birds are extinct. These percentages are probably not finally determinative of age, but they suggest a stage comparable to that of Hay Springs or Rancho La Brea and earlier than Conard Fissure or Samwel Cave.

Compared with the Rancho La Brea fauna that of Fossil Lake is characterized by absence of *Bison,* which are abundant at Rancho La Brea, and were evidently late arrivals in America. This peculiarity is balanced by absence of the small antelope, *Capromeryx,* and the

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imperial elephant, early types characteristic of Rancho La Brea. *Equus pacificus,* the common horse of Fossil Lake, is apparently a more specialized form than *E. occidentalis* of Rancho La Brea, and the prong-horn *Antilocapra* represented at Fossil Lake is apparently a specialized descendant derived from a stock near the Rancho La Brea *Capromeryx.* It may be that the Fossil Lake assemblage is not older than that of Rancho La Brea, but is merely a contemporaneous northern phase of the same fauna.

The absence of bison from the Fossil Lake fauna may be sufficient warrant for considering it older than the upper Lahontan stage, but this item may not be of greater value in separating the time of deposition of the two sets of deposits than is the physical evidence used by Gilbert to prove their contemporaneity.

If Gilbert is correct in his correlation of Fossil Lake with Lahontan and Bonneville, the Lahontan fauna belongs to a time separated from the present by a period of widespread extinction of organic types and by evolution or introduction by migration of an almost entirely new mammal series, as two-thirds of the Fossil Lake mammal species are extinct and the stage as a whole does not appear like the latest Pleistocene.

In some respect the closest resemblance of the few mammal fragments from the Lahontan is to the fauna of Rancho La Brea. Of the known Lahontan fauna—*Elephas columbi?, Equus* near *pacificus, Equus* near *occidentalis, Bison,* sp., *Camelops,* sp., *Felis atrox*—all of the forms so far as known, with the exception of the horse near *E. pacificus,* are found at Rancho La Brea. It seems possible that the Lahontan fauna may be representative of a period including the Fossil Lake and Rancho La Brea stages. On this basis it would appear that, whatever the more exact correlation, the Lahontan stage represents a time when the life of this region and that of North America in general was made up of mammal types of which from 60 per cent to 70 per cent have since become extinct and are replaced by new types.

We are not of course able to make an exact correlation for the whole of North America in Pleistocene time, but we know that many of the types included in the Rancho La Brea and Fossil Lake assemblages had a very wide geographic distribution, and it seems that a change such as has occurred since Rancho La Brea and Fossil Lake time is typical of a faunal change over a large part of America.

That an extinction of 66 per cent of the mammals in any fauna might occur in a very short time one might readily grant, but the

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origin of the new fauna replacing it is not so readily conceived. We may, I believe, assume that the existing fauna of the Lahontan region is not merely a reminder from a large Pleistocene fauna. The origin of the present fauna is not to be accounted for in this manner more easily than one would account for the origin of the existing earth fauna as a remainder from a Mesozoic life series gradually diminishing from period to period. The present fauna is to be accounted for in some part as a remainder and in part as a new development either out of ancestral American forms or out of immigrants from other regions. One might, of course, assume that the existing faunal types arose very recently as mutants developing in response to some great shock given by a physical change such as a great modification of climate, but no evidence has been advanced indicating that such change has ever taken place within a short time measured in terms of years. The rate of change of faunas is fairly known in relation to rate of sedimentation, and there seems to be on record no case in which such an extreme modification of life as is noted between the Rancho La Brea stage and the present has taken place in less than a considerable period measured in terms of deposition.

If we assume that the present fauna peopled America by migration, we encounter an obstacle no less difficult to overcome than that presented by rapid evolution without change of geographic situation, as migration from any other continent involves the crossing of great barriers of topography, and belts of varying temperature at least as important as hindrances to migration as are those of relief. Such migration as would be required presumably involves nothing less than general specific change of the migrating types, and a biological reorganization process which would take place slowly in the extension of the group by migration transverse to physical barriers.

The problem of fixing the date of the Lahontan fauna seems the same as that for other Pleistocene faunas containing a large percentage of extinct forms. An interpretation of the history of the Lahontan region as shorter than that commonly accepted, which measures the time in long periods expressed in terms of years, involves explanation of the extinction of a great variety of forms over a wide area, and appears to require the relatively sudden repeopling of this area either by more rapid evolution than we have reason to consider probable, or by a more rapid migration across barriers of temperature or of topography than we have reason to believe could occur without evolutionary changes in the migrating fauna.

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26. NEW MAMMALIA FROM THE IDAHO FORMATION

27. NOTE ON THE SYSTEMATIC POSITION OF THE WOLVES OF THE CANIS DIRUS GROUP

28. NEW PUMA-LIKE CAT FROM RANCHO LA BREA

BY
JOHN C. MERRIAM

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Vol. 10, No. 26, pp. 523-530, 5 text-figures April 20, 1918

NEW MAMMALIA FROM THE IDAHO FORMATION[1]

BY
JOHN C. MERRIAM

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INTRODUCTION

In attempting to work out a correlation scheme of the Cenozoic formations in the Great Basin region, the writer has found the Idaho formation particularly difficult to interpret with regard to its stratigraphic relations and to its fauna. In the summer of 1916 the principal exposures in southwestern Idaho were visited in company with Dr. J. P. Buwalda in the interests of the United States Geological Survey. In the course of this investigation a number of significant collections of mammalian remains were obtained. In the material secured there are a few new forms to which it is necessary to make reference in several papers discussing phases of the Idaho problem. A full discussion of the Idaho fauna with particular reference to its affinities will be presented in a later paper.

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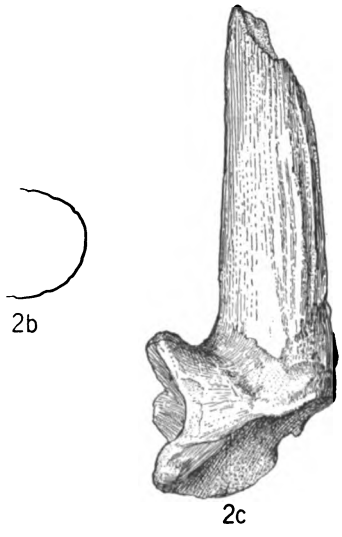

dgreni, n. sp. Horn-core. Type specimen, g. 2*a*, median view; fig. 2*b*, cross-section at w. From beds referred to the Idaho forma-o.

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ISCHYROSMILUS? IDAHOENSIS, n. sp.

Type specimen, no. 22343, from beds referred to the Idaho formation at locality 3036C, near Froman Ferry on the Snake River in southwestern Idaho. The type consists of the anterior two-thirds of the left ramus of a mandible with the roots of all of the teeth.

Specimen no. 22343 (fig. 1) represents a very large sabre-tooth approximating the dimensions of the largest individuals of *Smilodon californicus* from Rancho La Brea. The Idaho specimen differs from the typical *S. californicus* in dentition by the presence of a small $P_{\bar{3}}$. This tooth is found in a small percentage of the Rancho La Brea sabre-tooth specimens, but is normally absent. The Idaho mandible differs

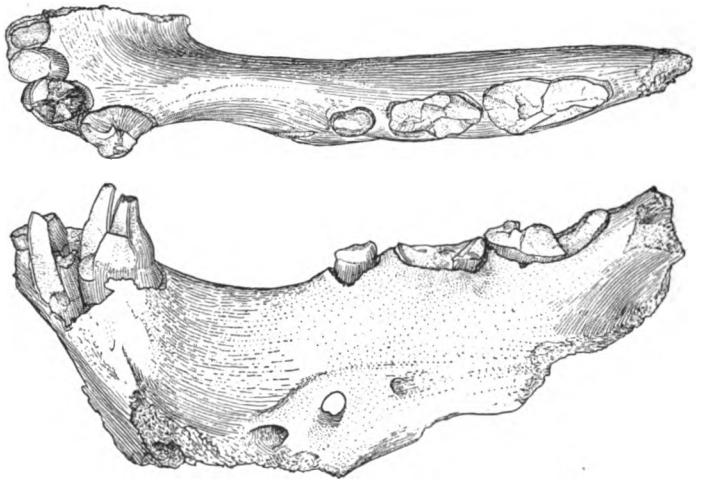

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Fig. 1. *Ischyrosmilus? idahoensis*, n. sp. Outer and superior views of mandible. Type specimen, no. 22343. × ½. From beds referred to Idaho formation, near Froman Ferry, Idaho.

from that of *S. californicus* very decidedly in the size and proportions of the flange below the diastema. In *S. californicus* the flange is comparatively short, ending posteriorly rather abruptly some distance in front of $P_{\bar{3}}$. In no 22343 the posterior end of the flange fades out below the anterior end of $P_{\bar{4}}$. A flange of the type seen in the Idaho specimen is found also in *Ischyrosmilus ischyrus* of the Tulare Pliocene

[2] *Ischyrosmilus*, new genus, founded upon *Machaerodus? ischyrus* Merriam. Genus characterized as follows: mandible massive; flange clearly marked, relatively wide anteroposteriorly, slightly wider than in *Smilodon*, not as strongly developed as in *Machaerodus;* diastema much as in *Machaerodus* but shorter than in *Smilodon*. $P_{\bar{3}}$ very small with one root. $P_{\bar{4}}$ with single posterior cusp or incipient division of this cusp. For more extended discussion, see Merriam, J. C., Tertiary Mammalian Faunas of the Mohave Desert Region, Univ. Calif. Publ., Bull. Dept. Geol., in press.

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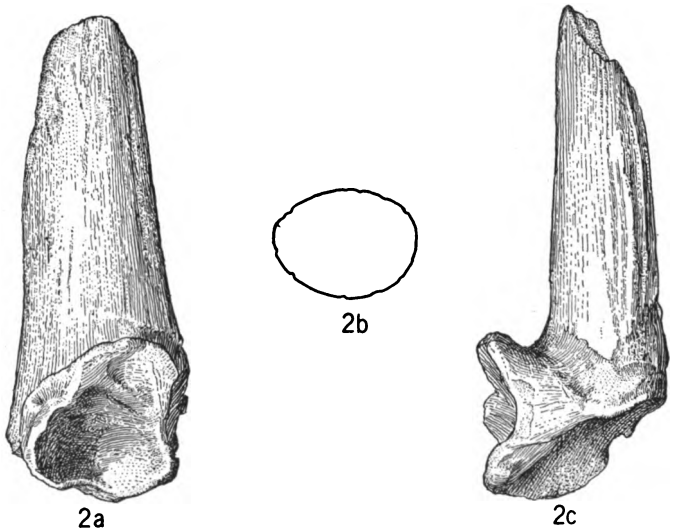
of California, in *I. osborni* of the Ricardo Pliocene, and in *Machaerodus palaeindicus* of the upper Siwalik beds of India.

The Idaho specimen possesses three mental foramina in contrast to the one large foramen seen in *Smilodon californicus*.

The tooth crowns in no. 22343 are unfortunately all broken away with the exception of a considerable part of the lower canine and about one-half of the crown of $P_{\bar{3}}$. Sufficient portions of the roots remain to give an estimate of the relative dimensions of the teeth. These measurements indicate that $P_{\bar{4}}$ is relatively smaller and $M_{\bar{1}}$ larger than in *S. californicus*. As these measurements are based upon the upper portions of the roots or upon the neck of the teeth they are not exactly comparable with the measurements from perfectly preserved crowns of *S. californicus*, as the lower region of the crowns has a somewhat longer anteroposterior diameter than the upper portion of the root or the neck.

The incisors of the Idaho form appear somewhat thicker transversely than in the typical species of *Smilodon* from Rancho La Brea.

With the fragmentary material available it is impossible to draw very satisfactory conclusions as to the systematic position and age of the Idaho sabre-tooth. The presence of a well developed $P_{\bar{3}}$ taken with the unusual anteroposterior diameter of the flange and the rela-



Figs. 2*a* to 2*c*. *Neotragocerus lindgreni*, n. sp. Horn-core. Type specimen, no. 3941, U. S. Nat. Mus. × ½. Fig. 2*a*, median view; fig. 2*b*, cross-section at middle height; fig. 2*c*, posterior view. From beds referred to the Idaho formation three miles east of Boise, Idaho.

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tively large size of $M_{\bar{1}}$ suggest affinity with the Pliocene genus *Ischyrosmilus* represented in the Ricardo and in beds referred to the Tulare, of California. *Machaerodus palaeindicus* of the Siwalik beds differs from all of these forms in possession of a two-rooted $P_{\bar{3}}$.

While it is true that $P_{\bar{3}}$ may be well developed in adult individuals of *Smilodon californicus* as in the Idaho specimen, this occurrence is so exceptional that the chance of having this tooth occur in an isolated individual would be very small.

So far as the evidence of this sabre-tooth is concerned, it might be presumed to suggest a somewhat earlier geologic stage than that of *S. californicus*. It should also be noted that the Idaho form is much larger than the specimens from the Ricardo and the Tulare and might therefore be later than the horizons represented by the Ricardo and Tulare faunas.

Comparative Measurements

	No. 22343 Idaho	I. ischyrus No. 8140 Tulare	I. osborni No. 19476 Ricardo	S. californicus No. 22180 Rancho La Brea
Height of mandible below anterior end of $P_{\bar{1}}$..	49 mm.	41.2	34.7	40.3
Thickness of mandible below anterior end of $P_{\bar{1}}$	22.2	.....	.....	18.3
Height of mandible below anterior end of $P_{\bar{3}}$..	52	41.4	36	37
Length anterior side inferior canine to posterior side $M_{\bar{1}}$	135.2	107	81	134.2
Length anterior side $P_{\bar{3}}$ to posterior side of $M_{\bar{1}}$	71.6	61.7	.....	65.5
Length of diastema	46.4	33.5	26.5	51.5
C, anteroposterior diameter	19.2	14.5	*a*10	16.2
$P_{\bar{3}}$, anteroposterior diameter	10	7	*a*6.4	9.9?
$P_{\bar{4}}$, anteroposterior diameter	23.7	20	16.7	25
$M_{\bar{1}}$, anteroposterior diameter	33.2	28.5	24	30
$M_{\bar{1}}$, greatest transverse diameter	13.5	15	11	15

a, approximate. All measurements of teeth approximate on neck or base of crown.

NEOTRAGOCERUS LINDGRENI, n. sp.

Type specimen, a horn-core, no. 3941, collection of U. S. Geological Survey assembled by W. Lindgren. Found three miles east of Boise, Idaho, by Edward S. White. Occurrence doubtfully in Idaho beds.

The horn-core (figs. 2*a* to 2*c*) obtained by Lindgren from the Boise region represents an antelope of the *Tragocerus* type and approaching the characters of the Snake Creek Pliocene form described as *Neotragocerus improvisus* by Matthew and Cook.[3]

[3] Matthew, W. D., and Cook, H. J., Bull. Amer. Mus. Nat. Hist., vol. 26, p. 413, 1909.

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The Idaho specimen is more slender than *N. improvisus,* and may show slightly greater lateral compression. It is also more slender, longer and more distinctly flattened transversely than horn-cores of the Recent mountain goat, *Oreamnos.* Additional material will be required before the position of the species represented by this specimen can be clearly determined.

EQUUS IDAHOENSIS, n. sp.

Type specimen, an upper cheek-tooth, no. 22348, from locality 3036C in beds referred to the Idaho formation near Froman Ferry on the Snake River, eight miles southwest of Caldwell, Idaho.

Referred to this species is also a lower premolar, no. 22347, from beds referred to the Idaho formation at Froman Ferry.

Cheek-teeth large and heavily cemented, characters as in typical *Equus,* excepting in the nature of the protocone of the upper cheek-teeth and of the inner gutter between metaconid and metastylid columns of the lower cheek-teeth.

Protocone very short anteroposteriorly but distinctly concave on the inner border. Character of the protocone approaching that of *Equus stenonis* of the European Pliocene. Gutter on inner border of metaconid-metastylid column of lower cheek-teeth narrow and angular as in *Pliohippus.*

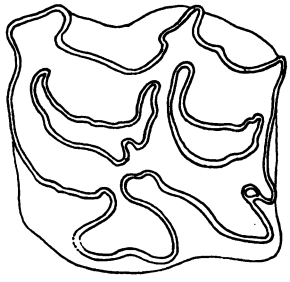

Fig. 3. *Equus idahoensis,* n. sp. P^4, occlusal view. Type specimen, no. 22348, natural size. From beds referred to Idaho formation, near Froman Ferry, Snake River, Idaho.

An upper tooth, no. 22348, from locality 3036C in Idaho beds near Froman Ferry on the Snake River represents an animal as large as *Equus pacificus* or the largest individuals of *E. occidentalis.* The crown (fig. 3) is very heavily cemented. Unfortunately it has suffered so much wear that the original length and curvature cannot be estimated. The fossettes are very narrow, as might be expected at this stage of wear, and show plications of such extent as to indicate that considerable folding of the walls would be shown at an early or middle stage of wear. The outer styles are strong. The outer walls of protocone and paracone are much flattened. The protocone is small and

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short anteroposteriorly, the stage of anteroposterior abbreviation suggesting that in *Pliohippus*. As in *Equus*, the anterior border of the protocone is prolonged anteriorly much beyond the isthmus, connecting the protocone with the protoconule. The inner border of the protocone is distinctly concave, as in *Equus*. The characters of this tooth are those of *Equus*, with the exception of shortness of the protocone, which suggests *Pliohippus*. The characters of the anterior and inner borders of this pillar are clearly those of *Equus*. Anteroposterior shortness of the protocone occurs in a few species of *Equus*, especially the earlier members of the group.

An upper cheek-tooth, no. 22346 (fig. 4), was obtained at locality 3039, in bluffs assumed to be Idaho exposed along the north bank of the Payette River, about four and one-half miles southeast of the town of Payette. The anterior portion of the protocone of this specimen is broken away. The characters of this tooth do not seem in any particular to differ from those of the *Equus*. The posterior portion of the protocone column is shorter than this region often appears in *Equus*, but matches the proportions commonly seen in *Equus occidentalis*. There is good reason for considering that this tooth represents a typical *Equus* species not far removed from *E. occidentalis*. It differs from average specimens of *E. occidentalis* in greater lateral compression of the fossettes, and in the more pronounced complication of the enamel borders of the fossettes.

A lower premolar, no. 22347 (fig. 5), from locality 3036C in presumed Idaho beds at Froman Ferry represents a large and very advanced horse. The crown is long and heavily cemented; the outer faces of the protoconid and the hypoconid are flat. The metaconid-metastylid column is long anteroposteriorly and the valleys anterior and posterior to this column are narrow transversely. In all these characters this tooth distinctly resembles *Equus*. In a single feature, namely, in the acuteness of the inner fold of the metaconid-metastylid column, this tooth shows resemblance to advanced forms of *Pliohippus*. In *Equus* the gutter is commonly broad and flat. Occasionally, however, it may be narrow and the inner end of the fold acute. On the whole this tooth is of the *Equus* type with only a single suggestion of *Pliohippus* in its structure.

Compared with the teeth of *Equus* from the Columbia River bluffs near Ringold,[4] Washington, upper tooth 22348 is somewhat larger and the protocone is much shorter anteroposteriorly. The upper tooth

[4] Merriam, J. C., and Buwalda, J. P., Univ. Calif. Publ. Bull. Dept. Geol., vol. 10, p. 256. 1917.

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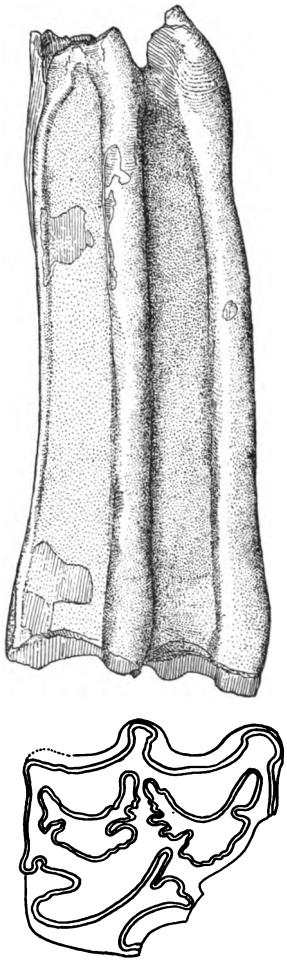
from the Idaho beds at locality 3039 is not apparently less Equus-like than the teeth from near Ringold, unless it be in the character of the anterior portion of the protocone, which is unfortunately broken away in the Payette River specimen. The portion of the protocone remaining in the Payette River specimen is perhaps a little thicker transversely than in the Ringold specimen, but a complete protocone might show more advanced lateral compression.



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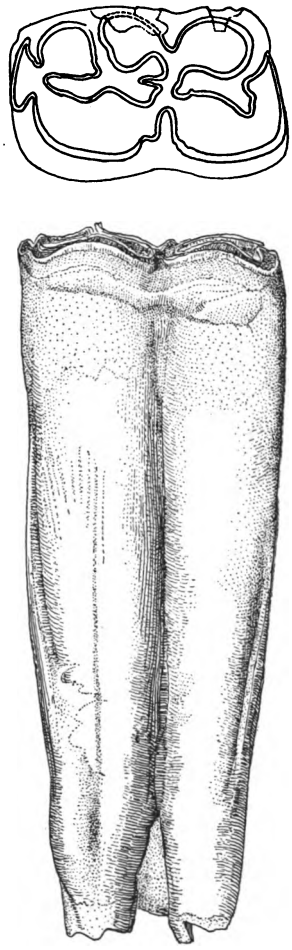

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Fig. 4. *Equus idahoensis?* M^{1}?, occlusal and outer views, no. 22346, natural size. From beds referred to Idaho formation, bluffs on north side of Payette River about four and one-half miles southeast of Payette, Idaho.

Fig. 5. *Equus idahoensis?* P_{3}, outer and occlusal views, no. 22347, natural size. From beds referred to Idaho formation, near Froman Ferry, Snake River, Idaho.

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The lower tooth from locality 3036C from the Snake River is slightly more Pliohippus-like than a large lower tooth from the exposures near Ringold. In the Idaho specimen the inner faces of the protoconid and hypoconid are a little less flattened, and the inner groove of the metaconid-metastylid column is much narrower and much more acute. In this respect the Idaho specimen is more Pliohippus-like than that from the beds near Ringold.

A number of specimens representing foot-bones of a large horse from beds referred to the Idaho show no evident characters distinguishing them from the corresponding elements of Pleistocene species of *Equus*.

COMPARATIVE MEASUREMENTS

	E. idahoensis P² ? No. 22348	E. idahoensis ? M² ? No. 22346	Large Individuals: E. occidentalis P²	Large Individuals: E. pacificus P²
Anteroposterior diameter	35.5 mm.	33	34	34.5
Transverse diameter	34.8	30.6	28.7	32.5
Height of crown	24.7	81	.....	.....
	No. 22347 $P_{\bar{4}}$		$P_{\bar{4}}$	
Anteroposterior diameter	34	.....	34.5	.....
Transverse diameter	18.8	.....	18.3	.....
Anteroposterior diameter of metaconid-metastylid column	19.8	.....	.....	.....
Height of crown	72	.....	.....	.....

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NOTE ON THE SYSTEMATIC POSITION OF THE WOLVES OF THE CANIS DIRUS GROUP[1]

BY
JOHN C. MERRIAM

In a study of the Pleistocene canid fauna of Rancho La Brea the writer had occasion some years ago to consider division of the wolf group into several subgenera. The principal evidence favoring splitting of the group was found in the wide difference between the dire wolf, *Canis dirus,* and all other representatives of the Canidae in North America. The only circumstance which prevented setting the wolves of the *C. dirus* group aside as a distinct genus or subgenus was the lack of such differentiation within this group as is to be expected in a generic division showing as wide a geographic range as that of the *C. dirus* forms. The suggestion was made that differentiation comparable to that characteristic of a genus was perhaps offered by the presence in the Rancho La Brea fauna of a second species of the *C. dirus* group, namely *Canis milleri.* The *milleri* form was described as a distinct species having characters approximating more closely to those of *C. dirus* than to the characters of the timber wolves of the *C. occidentalis* group.

Subdivision of the *Canis* group of America has already been proposed by other authors who would separate such distinct groups as the timber wolves and coyotes. Regardless of the question as to generic or subgeneric rank of these divisions, there seems to the writer no question concerning the necessity of this grouping in order to express the relationships and history of these forms.

The writer's view concerning the generic distinction of the wolves of the *C. dirus* group has received substantial confirmation through

[1] Read at eighth annual meeting of the Pacific Section of the Paleontological Society, Stanford University, April 6, 1917.

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the discovery of new material representing a wolf related to *C. dirus* in the Pleistocene of Florida. In his important paper on "Human Remains and Associated Fossils from the Pleistocene of Florida" Dr. E. H. Sellards[2] has described the first skull of a member of the dire wolf group found outside the California region.

The dentition of Dr. Sellard's specimen very closely resembles that of the type specimen of *C. dirus* from Indiana. These characters also fall well within the range of variation of the dire wolves of Rancho La Brea. The greater number of the unusual characters distinguishing the wolves of the *dirus* group are recognized by Dr. Sellards in his specimen from Vero. The Florida skull is, however, characterized by quite different proportions of the facial region, the nose and the palate being much narrower and more slender, and the premolar teeth more widely spaced than in the Rancho La Brea group. In view of these differences, Dr. Sellards seemed justified in separating the Florida wolf as a new species to which he has given the name *Canis ayersi*.

Considering that the several types included in the *dirus* group represent at least three quite distinct forms, in all of which there appears a group of common characters sharply distinguished from those of other wolves, there is ample justification for distinguishing this group as a separate genus or subgenus for which the name *Aenocyon*[3] may be applied.

The generic characters of *Aenocyon* are found in the massiveness of skull and dentition, extreme overhang of the inion, shortness of the basicranial region posterior to the glenoid fossae, massiveness of the upper and lower carnassials, reduction of the hypocone of M^1, and probably in characters of the skeleton not as yet available from other material than that obtained at Rancho La Brea.

The genus *Aenocyon* was widely distributed over North America in Pleistocene time. Its range extended from the east to the west coast and from Mexico at least as far north as the upper portion of the Mississippi Valley. Whether its geographic range extended into the Canadian area is as yet uncertain. It is possible that the timber wolves of the *Canis occidentalis* group occupied the northern portion of the continent contemporaneously with the maximum development of the *Aenocyon* group in the Sonoran region. The geologic range of *Aenocyon* is also still to be determined. A somewhat puzzling

[2] Sellards, E. H., 8th Ann. Rep. Florida Geol. Surv., pp. 152–57, pls. 24, 30, figs. 1, 3, 1916.

[3] Aenos: terrible, dreadful; cyon: wolf.

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feature in the distribution of these wolves is found in their absence from the Pleistocene of Fossil Lake, Oregon. The Fossil Lake deposits contain a large vertebrate fauna representing a wide variety of forms and ranging from the largest to the smallest mammals and birds, and including representation of some of the most delicate osseous structures. Wolf remains are well known in this fauna, including bones of both timber wolves and coyotes, but as yet no representation of *Aenocyon* has been recognized in the collections from this locality. Had *Aenocyon dirus* or any other member of the group been present in this region in numbers comparable to those known elsewhere in the Pleistocene it would presumably have left at least some trace of its presence. Its absence may be due to limited northern range, or to deposition of the Fossil Lake beds at a period earlier, or perhaps later, than that of Rancho La Brea and of other deposits in which specimens representative of *Aenocyon* have been found.

The recognized species of *Aenocyon* are *A. dirus, A. milleri,* and *A. ayersi.*

Aenocyon dirus[4] (Leidy) is represented in the Rancho La Brea fauna by a wide variety of forms, but always characterized by large size, massiveness of dentition, relatively great width of palate, and of facial region.

Aenocyon ayersi[5] (Sellards) is characterized by large size, relatively narrowness of facial region compared with *A. dirus,* massiveness of dentition, and relatively wide spacing of the premolars.

Aenocyon milleri[6] (Merriam) is distinguished in comparison with *A. dirus* and *A. ayersi* by smaller size, relatively low sagittal crest, and less prominent inion. The dentition is massive as in the other two forms and the premolars are closely set, as is rather common in *A. dirus.*

[4] See Merriam, J. C., The Fauna of Rancho La Brea. Part II, Canidae, Mem. Univ. Calif., vol. 1, no. 2, pp. 218–246, 1912.

[5] See Sellards, E. H., *op. cit.*

[6] See Merriam, J. C., *op. cit.*

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NEW PUMA-LIKE CAT FROM RANCHO LA BREA

BY
JOHN C. MERRIAM

Included in a considerable variety of representatives of the *Felis* group known from Rancho La Brea, there is a large puma-like cat representing a species distinct from any thus far described from North America. As the description of this species is necessary to certain studies on the Felidae now in progress, it is desirable to present a preliminary description at this time.

FELIS DAGGETTI, n. sp.

Type specimen, a mandible, no. 21572, from locality 2050, Rancho La Brea, California.

The mandible and dentition have approximately the dimensions found in the Recent puma of California, but are distinguished by unusual massiveness of the cheek-teeth and of the jaw, by unusual width of the angle of the mandible, and by the unusual backward curve or sweep of the coronoid process compared with that in Recent pumas.

This species is named in honor of my friend and colleague, Mr. Frank S. Daggett, Director of the Museum of History, Science and Art, of Los Angeles, whose interest and co-operation in study of the Rancho La Brea collections have contributed largely to the effectiveness of monographic studies on this fauna now in progress.

The *Felis daggetti* specimens represent an animal equaling or perhaps exceeding in size the largest pumas of the present day. They are apparently to be classed with the puma group rather than with the jaguars, and differ widely from the great cats of the *Felis atrox* type, with which they were associated. The lower jaw represented in the type specimen differs from that of the pumas of the *Felis*

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concolor type in relatively large size and massiveness of the cheek-teeth, in the extreme width of the posterior region of $P_{\bar{3}}$ and $P_{\bar{4}}$, and in the stronger backward curvature of the long coronoid process. From the jaguar specimens available for comparison the type speci-

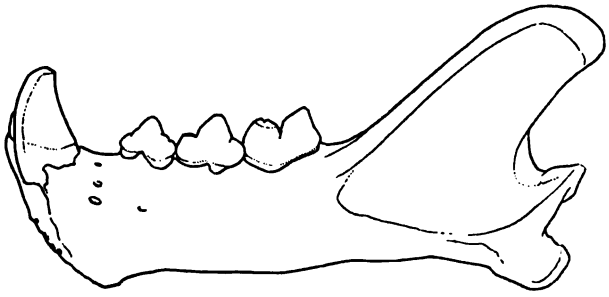

Fig. 1. *Felis daggetti*, n. sp. Outer view of mandible of the type specimen, no. 21572, × ½. From the Pleistocene of Rancho La Brea, California.

men differs in the more massive lower cheek-teeth, in the greater width of $P_{\bar{3}}$ and $P_{\bar{4}}$, in the relatively shorter anteroposterior diameter of $P_{\bar{4}}$, and to some extent in the greater degree of backward curvature of the coronoid process.

Several mandible specimens from Rancho La Brea show the characters of the type specimen of *F. daggetti*. Among these is the posterior portion of a lower jaw representing the first puma-like form recognized in the Rancho La Brea fauna.*

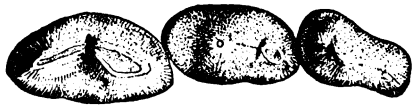

Fig. 2. *Felis daggetti*, n. sp. Dentition, occlusal view, type specimen, no. 21572, natural size, from the Pleistocene of Rancho La Brea, California.

MEASUREMENTS OF NO. 21572, TYPE SPECIMEN

Greatest length of mandible from anterior end of symphysis to middle of posterior end of condyle	145.7 mm.
Height of mandible below anterior end of $M_{\bar{1}}$	31.5
Height of mandible below anterior end of $P_{\bar{4}}$	27.6
Thickness of mandible below posterior end of $M_{\bar{1}}$	16.3

* Merriam, J. C., Univ. Calif. Publ. Bull. Dept. Geol., vol. 7, pp. 42 and 45, 1912.

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Height from lower side of angle to upper side of condyle	31 mm.
Anterior side of canine alveolus to posterior end of $M_{\bar{1}}$	79.5
Length of diastema between posterior side of canine alveolus and anterior side of $P_{\bar{3}}$	10.5
$I_{\bar{3}}$, greatest transverse diameter	3.1
C, anteroposterior diameter of alveolus	16.9
$P_{\bar{3}}$, anteroposterior diameter	14.7
$P_{\bar{3}}$, transverse diameter	9.1
$P_{\bar{4}}$, anteroposterior diameter	17.6
$P_{\bar{4}}$, transverse diameter	10.5
$M_{\bar{1}}$, anteroposterior diameter	21
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* Univ. Calif. Publ. Bull. Dept. Geol., vol. 10.

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